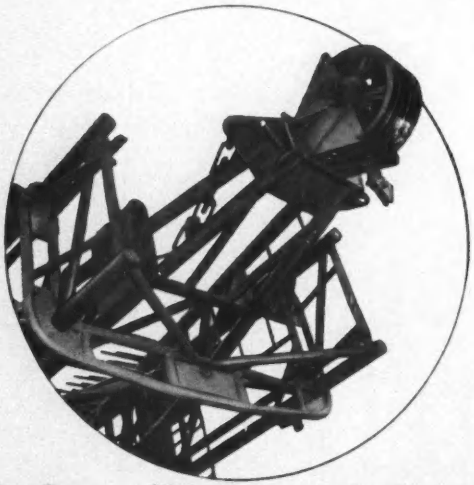
Vol. 13 No. 4 AUGUST, 1950

TRANSACTIONS OF THE INSTITUTE OF WELDING

(See Title Page)



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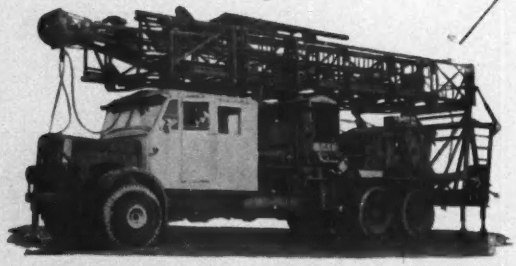

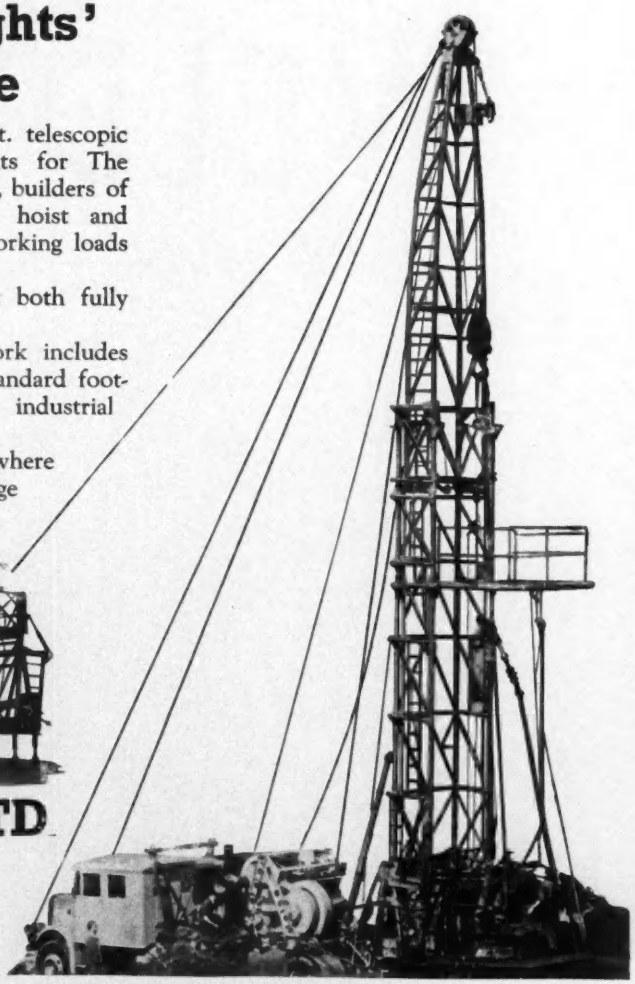

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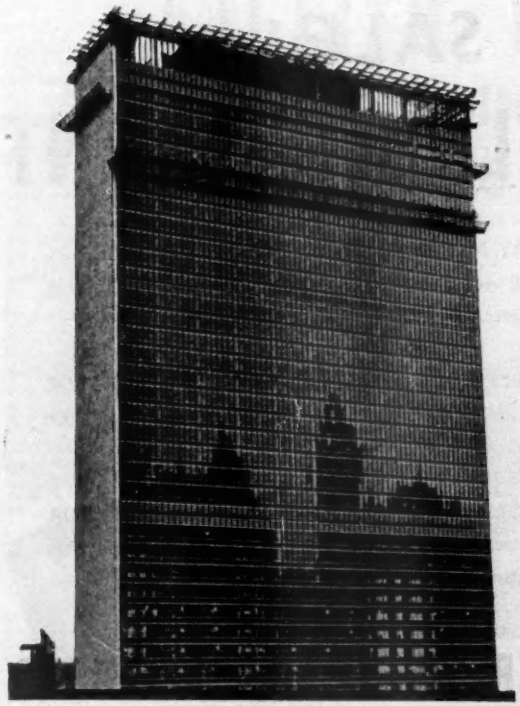

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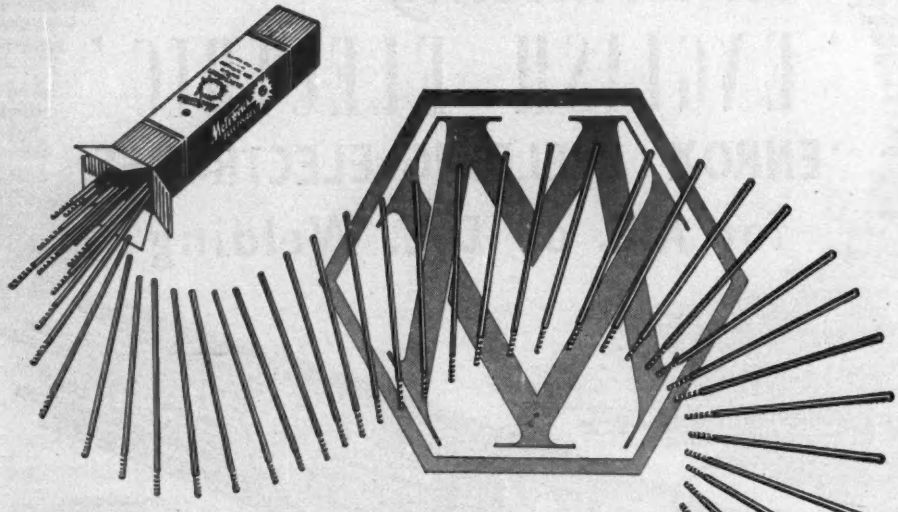

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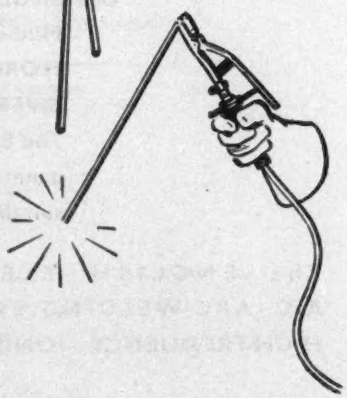
The last word in welding rests with the operator. The man on the job knows whether an electrode is easy to use, whether he gets good penetration without undercutting, has no difficulty with slag inclusions . . . All these practical everyday points are watched in the production of Metrovick electrodes, for M-V are themselves one of the biggest users of welding in the country. In their own shops they use Metrovick electrodes exclusively. This practical experience is reflected in the quality of all M-V welding equipment and electrodes, so that for anything in welding it is always best to rely on Metrovick.



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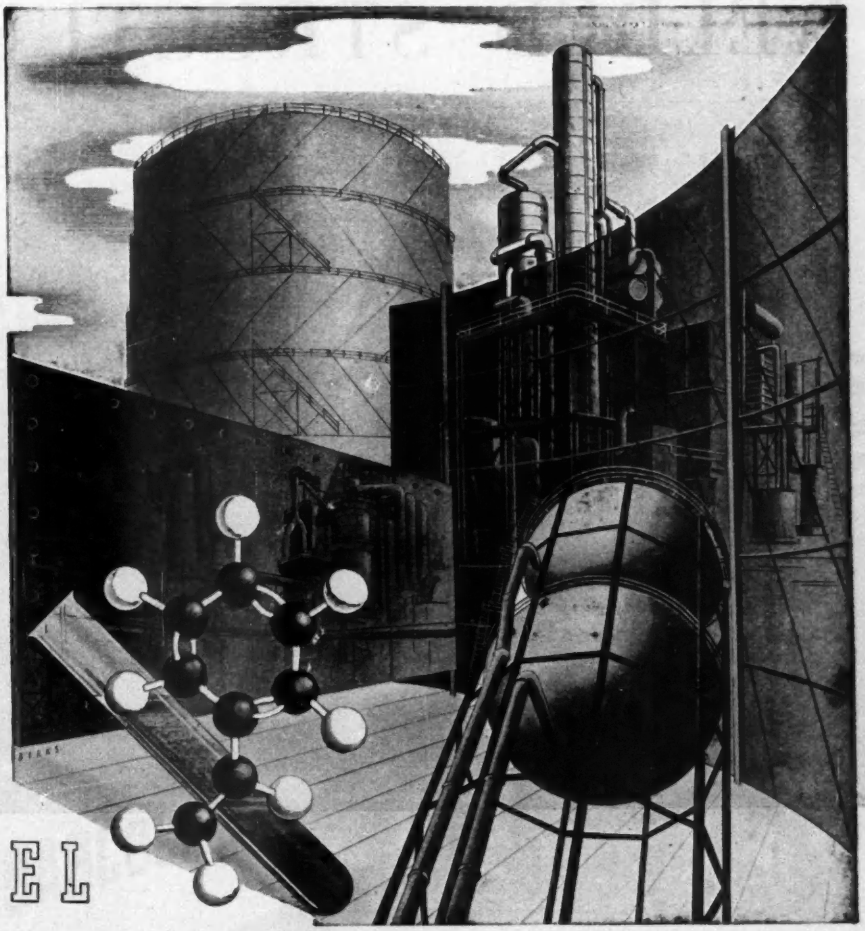

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OK UNITRODE ELECTRODES combine the above advantages with ease of use, and the high metal recovery of 115 per cent. ensures fast deposition speed. Clear visibility of the crater edge also contributes to the extreme ease with which vertical and overhead welding can be carried out.

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Further interesting information concerning OK UNITRODE ELECTRODES is contained in our Leaflet No. 48, which we shall be pleased to send upon request.

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TRANSACTIONS OF THE INSTITUTE OF WELDING

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Honorary Editor : D. S. WATT, B.Sc., M.I.N.A.

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INSTITUTE NOTES AND NEWS

Council Elections, 1950.—The results of the ballot announced at the Annual General Meeting on 12 July were as follows:—Officers elected unopposed—President, Mr. C. S. Milne; Vice-President, Mr. Howard J. Thompson, M.I.Mech.E.; Honorary Treasurer, Mr. W. E. Harriss. Representatives of Industrial Corporate Members—Mr. H. N. Pemberton, M.I.Mech.E., M.I.N.A., Dr. H. G. Taylor. Representatives of Fellows, Members and Associate-Members—Mr. E. Blakeborough, Mr. E. P. S. Gardner, B.Sc., B.Eng., M.I.Mech.E., Mr. W. A. Roy, B.Sc., M.I.Mech.E., Mr. E. Seymour Semper, M.I.Mech.E.

At the meeting, Mr. G. M. Boyd and Mr. S. M. Reisser, speaking on the annual report and accounts, voiced a number of criticisms and made certain suggestions as to the policy and administration of the Institute. These are being examined by the Council and the appropriate Committees.

Headquarters Premises.—At their meeting in May the Council decided to negotiate for the purchase of the lease of the present premises at 2, Buckingham Palace Gardens. At the time of going to press, it is not known whether the Institute will be able to secure the lease or not, and it would be better, therefore, to postpone comment until the position is known with certainty. All that need be said at the moment is that if the Council's offer is accepted, the Institute will be assured of convenient headquarters premises, adequate for its present needs, for a period of 30 years.

International Welding Congress.—The Executive Committee for the International Welding Congress of 1951, established by the five British member societies of the International Institute of Welding, has made substantial progress with the planning of the Congress, and it is expected that the preliminary announcement, inviting applications for membership, will be issued towards the end of the summer. The opening meeting will be held in London on 14 July, 1951, and the closing functions also in London on 21 July, but the technical meetings and discussions will take place in Oxford from 15 to 20 July inclusive. In the following week facilities will be provided for overseas guests to visit works in different parts of the country, under the guidance of the Branches of the Institute of Welding.

Though much of the time at Oxford will necessarily be reserved for meetings of the Governing Council and Commissions of the International Institute, it is hoped that a number of public sessions will be held, at which papers will be presented and discussed. It has already been agreed with the International Institute that one of these sessions should be devoted to papers on the Welding of Bridges and Structures and another to the Welding of the Wrought Light Alloys.

Programme.—In view of the holding of the International Welding Congress in Great Britain next July, it has been decided to discontinue the Autumn and Spring meetings of the Institute this year. The following is the programme of meetings arranged:—

25 October—Presidential Address.

15 November—Luncheon at the Café Royal.

Evening—Paper by Professor Torroja on "Welded Bridges and Hangars in Spain," followed by the showing of a short Swedish film on welded bridges.

31 January—Paper by Mr. W. S. Atkins on the "Margam Abbey Steelworks."

28 February—Sir William J. Larke Medal paper.

4 April—Paper on "Researches at Birmingham University into the Welding of the Light Alloys."

It is probable that in addition to the foregoing a whole day

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meeting will be arranged with the Joint Committee for Materials and their Testing.

Paris Meeting of the I.I.W.—The annual meeting of the International Institute of Welding took place in Paris from 5 to 10 June and was attended by nearly 200 delegates and representatives, many accompanied by their ladies.

The French Institute of Welding, which was responsible for the organisation, was warmly thanked and congratulated upon the excellent arrangements made, which enabled the Governing Council and Commissions to despatch a great deal of business with ease and pleasure. The reports of the Chairmen of Commissions, presented at a plenary session of the Institute, are to be published in duplicated form, so as to make available the technical results of the work of the past year. Copies will be distributed to the member societies of the International Institute of Welding and to all those who attended the Paris meeting, while others will be able to obtain copies for a small charge. It is probable that many of these reports will be printed in welding journals and we hope to include them in a future issue of Transactions.

The social programme included a dance, a reception at the Hôtel de Ville, a visit to the galleries of classical sculpture at the Louvre, a banquet given by the French Institute and a whole day visit to Chantilly and other places of interest in the Ile de France. The weather was excessively hot, but the members of the large British delegation seemed to have enjoyed themselves very well.

New Branch at Preston.—A petition signed by 59 members of the Institute resident in and around Preston for recognition of a Preston Branch was considered by the Council at their meeting on 12 July. The proposed Branch area is the North-West portion of England, the boundaries to be drawn so as to include Wigan and Horwich in the South but to exclude Southport and Bolton, and on the East to include Accrington and Clitheroe.

This Branch has been brought into existence by the combined efforts of the Liverpool and Manchester Branches, which co-operated to organise a series of meetings in Preston during the past session. The Council ordered a message of thanks and congratulations to be sent to the two Branches concerned. In accordance with By-law 28 notice is hereby given that objection to the recognition of the Branch must be given within one month of the publication of this notice and must be lodged with the Secretary of the Institute at 2, Buckingham Palace Gardens, London, S.W.1., in writing. Objectors must state the grounds of their objection.

Reprints.—Reprints of the following papers published in Transactions are available at the prices named:—R. G. Braithwaite and D. J. Davies, "Welding in Bridgework and Allied Structures." Paper, illustrations and discussion reprinted from the December and February issues. Price 2s. 6d. R. Weck, "An Account of M. Henri M. Schnadt's Ideas on the Strength of Materials and his Testing Methods." Reprinted from the April issue. Price 2s.

Handbook for Welded Structural Steelwork.—A revised reprint of the *Handbook for Welded Structural Steelwork*, which has been in the press for nearly two years, is at last available, price 10s. per copy, post free. The book incorporates a number of important corrections to the formulae on pages 111-118 of the fourth edition, but is otherwise identical with that edition. It is intended to circulate the corrections to the purchasers of the fourth edition.

Binding of Transactions.—The Index to Volume 12 of the *Transactions* for the year 1949 was printed in the February 1950, issue. Arrangements have been made for the binding of members' volumes of *Transactions* in black embossed leathercloth at a cost of 10s. 6d. each, plus 1s. for postage and packing. Members wishing to take advantage of this arrangement should forward parts, with index, to Mansell (Bookbinders) Ltd., 31, Cursitor Street, Chancery Lane, London, E.C.4.

Research Supplement.—With this issue of *Transactions* is included Volume 4, No. 3, of *Welding Research*, containing the following reports of the British Welding Research Association:

R.59.—The Welding of Thick Aluminium Alloy Plates by the Argon Arc Process by J. E. Chard and N. Macdonald.

R.60.—Some Extracted Notes on Hastletoy and Fabricated Welding.

Reading of Papers.—Members of the Institute who would be prepared to read papers at meetings of the Institute or of its Branches are invited to forward the papers (or descriptive summaries) for consideration by the Programme and Journal Committee. Papers submitted in response to this invitation should reach the Secretary of the Institute not later than 16 September, 1950.

Examination Regulations.—Copies of the following document are available gratis to members on application to the Secretary of the Institute:—"Examination Regulations and Syllabuses."

British Standard.—The following British Standard has now been issued:—B.S. 1654: 1950. Electrically Welded Mild Steel Boiler and Superheater Tubes. Copies are available from the British Standards Institution, 24-28, Victoria Street, London, S.W.1. Price 2s. net, post free.

Italian Metallurgical Association.—The Associazione Italiana di Metallurgia announce the holding of their fourth annual convention at Florence from 28 September to 1 October next. Particulars have also been issued of the Luigi Losana Gold Medal, which is to be awarded in alternate years to the Italian or foreign researcher who is adjudged to have made the most important contribution in his own country to the knowledge of metals. Details both of the convention and of the statutes for the award of the Medal may be had from the Secretary of the Institute.

B.A.A. Luncheon.—The annual luncheon of the British Acetylene Association was held at the Connaught Rooms on 22 June last, the President of the Association, Mr. Herman Hirst, presiding. The toast of the Association was proposed by Sir William Larke, K.B.E., and the Chairman responded. Other speakers were Mr. Eric Stein, Vice-President and President designate, Dr. Watts, G.M., Sir Charles Lillicrap, Mr. A. Hoddle and Mr. A. Stephenson.

The Association celebrates its jubilee next year, and it was announced at the luncheon that the Commission Permanente Internationale de l'Acétylène of Paris had accepted an invitation from the Association to hold their annual meeting in Great Britain next year.

A Boulton-Watt Engine Retires.—An interesting feature of the Grazebrook bi-centenary celebration was the handing over to the City of Birmingham of a Boulton-Watt blowing engine, installed by M. & W. Grazebrook Ltd., in 1817 and in use as late as 1936. The presentation was made at a commemorative luncheon, held in the Town Hall, Dudley, on 15 June last, when Mr. O. F. Grazebrook, the Chairman of the Company, presided over a large and distinguished gathering. The toast of the Company was proposed by the Lord Mayor of Birmingham (Alderman A. Paddon Smith, J.P.), supported by Mr. J. R. Menzies-Wilson, O.B.E., and the response was made by Mr. O. F. Grazebrook. Mr. C. J. Grazebrook proposed the toast of the Guests, to which the Mayor of Dudley (Councillor G. S. Marlow, J.P.) replied. After luncheon the guests were taken to the company's works, where they were able to inspect the blowing engine and to make a tour of the shops. The commemorative booklet gives an interesting account of the history of the company, which has remained in the possession of the Grazebrook family since its foundation in 1750, and of the varied products of its foundry and fabrication shops.

Metals in the Service of Mankind.—Welding will have an important place in the special exhibition under the above title which is to be held at the Science Museum, South Kensington, from 7 July to 30 September. The exhibition has been organised by the Institute of Metallurgists in conjunction with the Science Museum, the major research and development associations, firms working in the metallurgical fields, and the welding section has been the special care of the British Welding Research Association. Beside the historical exhibits, the modern practice in the extraction and refining of the common metals will be fully illustrated and some of the varied uses to which the metals are put will be shown, as well as such processes as electro-depositions, surface finishing and powder metallurgy. There will be a metallurgical laboratory and a metal testing section to illustrate techniques adopted to ascertain the composition and properties of metals. The exhibition will be open daily from 10 to 6 p.m. on weekdays and from 2.30 to 6 p.m. on Sundays.

INSTITUTE MEMBERSHIP

The following elections were made by Council on 31 May and 12 July:—

Members.—C. C. Bates (transfer from Associate-Membership), London, W.1.; H. O. Bradshaw, A.M.I.Mech.E. (transfer from Associate-Membership), Northfield, Birmingham, 31; D. P. Brown, B.Sc., New Jersey, U.S.A.; N. D. Brown (transfer from Associate-Membership), Staines, Middlesex; H. Waugh, Giffnock, Glasgow.

Associate-Members.—S. Basu, B.Sc., A.M.I.E. (Ind.), Calcutta, India; H. Baxendale, Newton Heath, Manchester, 10; B. Bhattacharya, A.M.I.E. (Ind.), Calcutta 6, India; R. G. Blackburn (transfer from Associateship), Birmingham; W. B. Brown (transfer from Associateship), Hong Kong; W. E. Bryant (transfer from Associateship), South Norwood, S.E.25; T. Cronshaw, Colne, Lancs; S. H. Cuttell (transfer from Graduateship), Sale, Cheshire; H. E. Dent (transfer from Associateship), Broadstairs, Kent; R. Devonald, Romford, Essex; J. J. Driscoll (transfer from Associateship), Dartford, Kent; D. W. Emery, B.Sc., Birkenhead, Cheshire; A. Fielder, Middle Herrington, Sunderland; J. W. Fomm, London, N.W.5; D. A. Hale, Smethwick, Staffs; G. C. Harper, Chingford, Essex; W. L. Lee, Caergwrle, near Wrexham; J. Lewin (transfer from Graduateship), Brixton Hill, S.W.2; E. M. Lloyd, Toronto, Canada; D. Loudfoot, Glasgow, S.W.2; C. C. Macfarlane, Eaglesham, Renfrewshire; G. Mackie, Dublin, Eire; H. A. Robinson, Sunderland; J. D. N. Sharrock, Norwood Green, Southall, Middlesex; A. Sills (transfer from Associate), Lower Wortley, Leeds, 12; A. Szumowsky, Whalley Range, Manchester, 16; H. K. Taylor, B.Sc., Pyrford, near Woking; T. Tonks, Birmingham, 29; G. Wade (transfer from Studentship), Sutton-in-Ashfield, Notts; F. Westall, Blackburn, Lancs; R. B. Whalley (transfer from Associateship), Wednesbury, Staffs; H. E. Wheeler, Wolverhampton, Staffs.

Companions.—R. M. Bairstow, Ovenden, Halifax; J. W. W. Ellison, Shirley, Croydon, Surrey; A. Fuller, Twickenham, Middlesex; W. H. A. Moore, Coventry; N. H. Sanders, Chesham, Bucks; D. M. Stuart, Rancagua, Chile; D. A. G. Weddell, London, N.W.2.

Graduates.—W. H. Batham, Woodside, Dudley, Worcs.; H. S. Drew, Tipton, Staffs; F. M. Jones, Holywell Green, Halifax; M. H. Lummus (transfer from Studentship), Luton, Beds; R. N. Rhodes, Castlefields, Bingley, Yorks; W. Sadler, Thornaby-on-Tees, Stockton-on-Tees; D. F. Shaw, G.I.Struct.E., Leeds, Yorks.

Associates.—R. Allen, Newmarket, Co. Cork. Ireland; J. H. Auckland, Llanelly, Carms; W. Awdas, Sheffield, 11; J. D. Bane, Peterborough, Northants; A. G. Barber, Croydon, Surrey; G. Bayley, Wednesbury, Staffs; C. B. Brown, Nottingham; J. Butler, Bamber Bridge, Preston, Lancs; A. M. Cameron, Troon, Ayrshire; J. B. Carr, Ilford, Essex; J. G. Christmas, Forest Gate, London, E.7; I. R. Collins, Newport, Mon.; R. Dearlove, Farnborough, Hants; A. W. Farrall, Kirkdale, Liverpool, 4; D. R. Flint, Radford, Nottingham; P. Gilbody, Sheffield; F. W. Grant, Humberstone, Leicester; L. S. Griffin, R.E.M.E., B.A.O.R.16; R. W. Griggs, Runcorn, Cheshire; A. W. Haines, Luton, Beds; J. Henthorne, Penwortham, Preston, Lancs; W. Hillhouse, Abadan, Iran; J. H. Inman, West Ewell, Surrey; L. S. G. Jefferies, Walkerville, Newcastle-on-Tyne, 6; G. F. Johnson, Earith, Hunts; R. C. Lamont, Dundee, Angus; F. Matthews, Far Cotton, Northampton; G. F. Murrell, Fulham, S.W.6; G. E. Nash, R.A.F., Weeton, Lancs; J. Nuttall, Clifton, Preston, Lancs; A. J. Olden, Marshfield, nr. Chippenham, Wilts; J. J. Orton, Chapel Allerton, Leeds, 7; E. S. Price, Stafford; A. Radmore, Enfield, Middlesex; H. Rees, Porthcawl, South Wales; J. H. Roberts, Greet, Birmingham, 11; S. Robinson, Featherstone, nr. Pontefract, Yorks; W. M. Russell, Longridge, nr. Preston, Lancs; G. L. Scott, Pallion, Sunderland; K. E. Swinnock, Portsmouth, Hants; G. Taylor, Longridge, nr. Preston, Lancs; C. Thompson, Preston, Lancs; G. H. Thomson, Greenock, Scotland; A. V. Valentine, Blackpool, Lancs; J. G. Warren, Lowestoft, Suffolk; G. D. Wearing, Pilling, nr. Preston, Lancs; A. E. Webb, Waverley Park, Glasgow, S.1; W. Webster, Northallerton, Yorks; G. Whiteside (transfer from Studentship), Lancaster, Lancs; D. J. Williams, Glais, nr. Swansea, Glam.; S. H. Williams, Birkenhead, Cheshire; R. Wilson, Ossett, Yorks.

Student.—G. D. Hawkins, Wallasey, Cheshire.

Industrial Corporate Members, Class 1.—Docks and Inland Waterways Executive, London, N.W.1; Empyrium Welding & Manufacturing Co. Ltd., Aston, Birmingham, 6; Evershed and Vignoles Ltd., Chiswick, London, W.4.

INSTITUTE OF WELDING MEETINGS

The following is a list of Institute of Welding meetings arranged for the months of September and October, 1950, so far as particulars are available at the time of going to press:—

7 Sept. **Tees-side Branch**
Visit to I.C.I. at Wilton, Middlesbrough.

9 Sept. **Liverpool Branch**
Visit to Vulcan Foundry, Newton-le-Willows.

16 Sept. **Southampton Branch**
"Welding in Locomotive Construction and Repair," by F. Hargreaves, A.R.S.M., D.I.C.

20 Sept. **Wolverhampton Branch**
Chairman's Address.

22 Sept. **Leeds Branch**
"Grinding Wheel Applications," by B. Bromage.

28 Sept. **North London Branch**
"The Resistance Welding of Light Alloys," by C. A. Burton (at the Regent Street Polytechnic).

30 Sept. **East of Scotland Branch**
Visit to North of Scotland Hydro Electric Board Stations.

4 Oct. **Manchester Branch**
"Notes from my Welding Experience," by G. Davenport, A.I.N.A.

5 Oct. **Tyneside Branch**
"Some Aspects of Shipyard Welding," by C. H. White.

5 Oct. **Tees-side Branch**
"The Margam Project," lecture and film by E. Ibbotson.

5 Oct. **Eastern Counties Branch**
"Photo-Elastic Methods of Stress Analysis," by Mr. Frankl (at Norwich).

6 Oct. **Eastern Counties Branch**
"Photo-Elastic Methods of Stress Analysis," by Mr. Frankl (at Colchester).

10 Oct. **Southampton Branch**
Visit to British Railways, Eastleigh.

10 Oct. **Liverpool Branch**
"A Welder's View of Ship Repairs," by G. Davenport, A.I.N.A.

12 Oct. **South London Branch**
Film Meeting.

13 Oct. **South Western Branch**
"Some Considerations in the Design and Detailing of Welded Structural Steelwork," by H. Roscoe.

14 Oct. **Birmingham Branch**
Chairman's Address.

17 Oct. **Sheffield Branch**
"Thermit Welding," by A. McConnell, with film and demonstration.

17 Oct. **East Midlands Branch**
"Hardfacing," by M. Riddihough, M.Met., A.R.I.C. F.I.M. (at Nottingham).

18 Oct. **Wolverhampton Branch**
"Recent Developments in Resistance Welding Technique," by C. A. Burton.

18 Oct. **West of Scotland Branch**
"Welding and Erection of Plate Girder Bridges," by W. Girvan.

26 Oct. **Leeds Branch**
"Welded Bridges and some Comparisons with Riveted Alternatives," by S. M. Reisser, B.Sc.

26 Oct. **North London Branch**
"Recent Developments in Argon-arc Welding."

27 Oct. **East of Scotland Branch**
Film Night (at Edinburgh).

NOTES FROM THE BRANCHES

Liverpool and Wolverhampton—Inter Branch Meeting.—A joint meeting of nearly seventy members and their ladies of the Liverpool and Wolverhampton Branches met in Chester on 10 June, 1950. During the morning the gentlemen visited the Stanlow refineries of the Shell-Mex concern, while the ladies made a tour of the city of Chester, which is well within the southern boundary of the Liverpool and District Branch. The reception of the gentlemen at Stanlow was very gratifying, and the visit began by a brief lecture outlining the activities of the great oil industry carried on within the 1,800 acres of towers, tanks and furnaces. There followed a tour of this plant under the guidance of two representatives of Shell-Mex. From a technical point of view this was highly instructive and gave members visual evidence of the uses to which welding has been put in the oil-refining industry. Miles upon miles of pipe lines of all shapes and sizes have welded flanges, joints and bends. The great cracking towers are of welded construction, and Wolverhampton members familiar with the pressure vessel industry were able to recognise many units which had been constructed in their own works. The tall tower from Hurrey's of Woolwich was also pointed out together with many similar products of Babcock and Wilcox. Cylindrical and spherical storage tanks in the Thornton area are constructed with welded joints in contrast to the older tanks in the earlier constructed northern section of the great plant.

The chemical solvents plant at Thornton is a thriving new British industry which is helping to reduce Britain's dollar deficit. The older process of crude oil distillation for kerosene has now been developed by the introduction of cracking to secure an increased yield of motor spirit and an almost endless range of marketable by-products having inestimable value for industrial, medical and domestic purposes.

Cracking is a regenerative process which involves the breaking-up of heavy hydro-carbon molecules into lighter ones. Crude oil is subjected to heat under pressure to produce gasolene and the gases ethylene, propylene and butylene, known as the defines. At first these gases were burned for fuel, but it has now been discovered that by suitable treatment they can be turned into useful new substances, including the chemical solvents acetone, alcohol and ether.

One of the principal by-products is Teepol, a synthetic detergent of which 75,000 tons are made every year by the plant under review. Teepol has come to influence present-day hygiene to a remarkable extent, and new cleaning agents based on Teepol have made good the shortage of fats for soap making.

The chemical solvents now play an important part in modern civilisation and nearly every industry uses them at one stage or another. Industries such as paint, leather, food processing and photography are chemical solvent consumers. Plastics, rubber finishes, fine chemicals and drugs can all be produced by processing gases which were once consumed as fuel.

A visit to Stanlow is a most impressive experience for welders who can there realise how vast a quantity of gas and liquid is sustained by the homogeneity of welded joints in the multitudinous steel tubes and cylinders of this ultra-modern refinery equipment.

The Liverpool and Wolverhampton Branches of the Institute of Welding were very grateful for the opportunity to visit Stanlow and appreciated the hospitality of the Shell-Mex Company and the excellent facilities offered.

After luncheon in Chester the combined parties visited West Kirby where outdoor competitions had been arranged, and took tea at New Brighton.

Manchester.—The Manchester and District Branch held its Annual Dinner on 17 March, 1950, at the Reform Club, Manchester. The Dinner was presided over by Mr. I. H. Hogg, the Branch Chairman, and the principal guests were Dr. J. S. Clarke, Dr. J. H. Paterson, Mr. G. Parsloe and Mr. W. Hart.

The toast, "The Institute," was proposed by Dr. Clarke and responded to by Dr. Paterson. Mr. H. St.G. Gardner proposed the toast "The Guests," and Mr. W. Hart, a Founder Member of the Manchester Branch, replied. Mr. G. Parsloe, Secretary of the Institute, proposed the toast to "The Branch," and Mr. I. H. Hogg, Chairman of the Branch, replied. A most enjoyable evening was spent by some 95 members and visitors who attended the dinner.

The third meeting arranged jointly by the Liverpool and Manchester Branches at Preston took place on 22 March, 1950, when two films were shown. Mr. Hart of the Manchester Branch acted as the Chairman, and after brief reference to the object of the meetings in Preston, he introduced Mr. McWilliam of the Firth-Vickers Company, who gave a short introductory talk on the first of the films to be shown. This was entitled "The Manipulation and Welding of Stainless and Heat Resisting Steels." This interesting colour sound film dealt with the fabrication of stainless and heat resisting steels and included metallic arc, oxy-acetylene, argon arc and resistance welding processes.

Mr. McWilliam then dealt with the numerous questions raised by members of the audience.

The second film shown was an American colour sound film, entitled "This is Resistance Welding," which showed typical examples of the use of spot, projection and seam welding in the production of a wide variety of components.

A vote of thanks was proposed to Mr. McWilliam and the Chairman thanked the Firth-Vickers Stainless Steel Company for the loan of the first film, and the Johnson-Matthew Company for the second film. He also expressed the thanks of the audience to Mr. Wilson who had kindly operated the projector equipment.

A petition was circulated by the Manchester Secretary, Mr. Fitch, so that any members present could sign it who were interested in the formation of a Preston Branch of the Institute of Welding. The meeting was attended by some 75 members and visitors.

The Branch Annual General Meeting was held on 12 April, 1950, and was followed by a film show. Mr. H. St.G. Gardner presided at the meeting at which about 35 members were present. Mr. Gardner indicated that under the rules of the Institute, Mr. Fuchs and Mr. Hart could not take office for the next session, and said that Mr. Hart would probably be leaving to join the proposed Preston Branch. Mr. Exton expressed the Branch's appreciation for the valuable services rendered by these two members to the Branch. Mr. Gardner stated that in view of the fact that there had been only one nomination outside the Committee's recommendations and, furthermore, that there was one vacancy on the Committee, there was no need for a ballot in deciding the new Committee. The Chairman then gave the composition of the officers and committee for 1950 as follows:—

Chairman, Mr. H. St.G. Gardner; *Vice-Chairman*, Mr. H. E. Lardge; *Hon. Treasurer*, Mr. W. L. McIvor; *Hon. Secretary*, Mr. I. C. Fitch; *Committee*, Mr. Grosvenor, Mr. Ferguson, Mr. Bushell, Mr. Wright, Mr. Heeley, Mr. Exton, Mr. Morgan.

The Chairman then called on the Secretary, Mr. Fitch, to read the Secretary's report. The report indicated that an increase in Branch membership had occurred during the Session but, as the Secretary pointed out, when the new Preston Branch was formed, he expected approximately 40 members would be lost to the Manchester Branch, and it was, therefore, most desirable that all members should endeavour to recruit new members for the Branch. The Hon. Treasurer, Mr. McIvor, was unfortunately unable to attend the meeting, and the Secretary read out an abridged version of the Treasurer's report.

The Branch was fortunate in having as a visitor Dr. H. G. Taylor, Director of the B.W.R.A. In answer to a request from the Chairman, Dr. Taylor spoke briefly on the work of the B.W.R.A. and its future programme, particularly with reference to the two new mechanical testing machines which they expected to have installed and working in the near future.

The meeting was concluded by the showing of the films "Manipulation and Welding of Stainless and Heat Resisting Steels," kindly loaned by Firth-Vickers Stainless Steel Company, and "This is Resistance Welding," kindly loaned by Johnson-Matthey & Company Ltd.

THE ARGONARC WELDING OF STAINLESS STEEL SHEET

By J. F. LANCASTER, B.Eng.

There has always been a demand for a method of welding which does not require the use of a flux, particularly for the aluminium and magnesium alloys, where corrosive flux residues can be a serious disadvantage. The argonarc welding process has to a large extent supplied this need. Light alloys, some copper-base alloys, and stainless steels are all weldable in this way, and it has been found that in addition to its other virtues argonarc welding can usually produce a sounder, stronger, and neater joint than the older methods. It is this latter quality, combined with its flexibility as a welding tool, which most recommends the argonarc process for stainless steel. In particular, it has marked advantages for fabricating vessels for the food industry, where it is frequently essential to polish out welds, and where defects such as porosity cannot be tolerated for bacteriological reasons. Furthermore, the small amount of reinforcement as compared with metallic arc weld reduces the amount of grinding required, thus mitigating a recurrent problem of stainless steel fabrication.

This paper, awarded the special commendation of the examiners in the Sir William J. Larke Medal Competition of 1949, *is concerned with the background work involved in the development of argonarc welding for such applications, and with an appraisal of its cost, as compared with other processes, under present conditions.*

Equipment

The basic principles of argonarc welding have already been described in a number of papers,[1,2,3,4,5] and it is unnecessary to enumerate them here. There remains, however, a controversial point concerning the equipment for stainless steel welding, *i.e.* whether alternating or direct current should be used. The possibility of using an A.C. generator was considered at an early stage, but it was found that in order to strike and maintain a steady arc it was necessary to incorporate a high frequency ioniser in series with the welding circuit. This necessarily makes the equipment more complicated and adds to the difficulty of using auxiliary electrical gear, since all electrical circuits must be protected from the effects of high frequency current. In the interests of simplicity and economy, therefore, it was decided to use D.C. with high frequency equipment, and the results which have been obtained have undoubtedly justified this decision.

Weld Quality

Before attempting to use argonarc welding in production, sample welds in titanium-bearing and molybdenum-bearing "18/8" steels were prepared and were compared for tensile strength, microstructure and corrosion resistance with similar welds made using the commercial coated electrodes. The nominal composition of the two steels used, A and B, is shown in Table 1. Argonarc welds were made with and without filler rod, the rod used being of the same composition as the parent metal, whilst for the arc weld a columbium-bearing rod was used for steel A and a rod containing 3 per cent. molybdenum for steel B.

Table 1

Steel	Composition				
	C	Cr	Ni	Ti	Mo
A	·12 max.	18	8	0·6	—
B	·12 „	18	8	—	2·75

Tensile Tests

Pairs of 6 in.×3 in.×16 s.w.g. strips were welded together to make 6 in.×6 in. panels, reinforcement was ground off and the samples were cut at right angles to the weld line into ½ in. strips. These were then fractured using a Hounsfield Tensometer, and values for the ultimate tensile strength and elongation were compared with those for unwelded strips cut from the same parent metal. These results, which are the average of four determinations in each case, are set out in Table 2.

In both cases the samples were welded on the bench in the down-hand position by the same operator, no backing-plate or jig being used.

Micro-examination

Sections taken from the welds made for tensile tests were examined under the microscope. The microstructures of argonarc and metallic arc welds were generally similar in both type "A" and type "B" steels.

Fig. 1 shows the difference in weld profile. The amount of reinforcement, in the case of the argonarc weld, is considerably less, and the penetration is wider than that of the metallic arc weld.

For the corrosion tests 3 in.×1 in. samples were cut from the original panels for these tests; reinforcement was ground off and the specimens polished on both sides.

Weld Decay

The argonarc welds were made either without filler material, or with the addition of wire containing titanium as the stabilising element. Since there might have been a tendency for the titanium to burn out during welding, tests were made on the weld metal as well as the parent metal, by welding across the sample pieces and subjecting them to the standard weld-decay test in boiling copper sulphate/sulphuric acid solution.

No sign of intergranular corrosion was found in any of the argonarc specimens subjected to this treatment. Evidently the amount of oxygen present in the arc atmosphere was not sufficient to cause preferential oxidation of titanium.

No comparison was made with metallic arc welded specimens, since it had previously been found that welds made with titanium-bearing rods were, under the conditions of this crossweld test, subject to weld decay, whereas welds made with columbium-bearing rods were unaffected.

Activation

Type A welds, with and without filler rod, were tested for activation in 10 per cent. (by volume) acetic acid with the addition of 2½ per cent. sodium chloride. Type B welds without filler were tested in two solutions:

(*a*) 50 per cent. acetic acid with 2½ per cent. sodium chloride added;

(*b*) 80 per cent. acetic acid with 2½ per cent. sodium chloride added.

Samples were totally immersed in the boiling solution for 16 hours,

and were then compared with standard metallic arc welds subjected to the same treatment. Results are shown in Table 3.

In general, it was evident that a weld of higher quality could be produced by the argonarc process than was possible using traditional methods. The improvement in ultimate tensile strength was not in itself important for the applications in question; however, the relative freedom from pinhole porosity which probably gave rise to the improved mechanical properties was a considerable advantage. In addition, the corrosion tests showed that this method could produce weld metal, the corrosion resistance of which was very close to that of the parent metal—an important point in fabricating vessels required to withstand severe corrosive conditions.

On the other hand, a few trials showed that argonarc welding was not without technical difficulties, and apart from the adjustments which are inevitable when a new method is used for production work, two problems were found to demand immediate attention.

Weld Profile

The first of these problems arose in connection with the welding of free-cutting stainless steel. Titanium stabilised stainless steels having the type analysis C 0.12 per cent., Cr 18 per cent., Ni 8 per cent., Ti 0·6 per cent., gave little trouble in welding. With care it was possible to produce a weld with good penetration and a flat top surface without the addition of filler rod. This was particularly the case with titanium-bearing steels containing a proportion of silicon; during welding a dense and apparently viscous layer of slag formed on the surface and tended to prevent any undercut. On the other hand, low carbon- (weldable) and molybdenum-bearing steels formed a much thinner slag which permitted the weld metal to sink away.

Free-cutting stainless steel, which contains a proportion of sulphur or selenium, was, however, more difficult to weld. When attempts were made to produce the fitting shown in Fig. 2, which consists of a right-angled tubular bend welded to a liner machined from "free-cutting" bar, severe undercut occurred along the edge of the weld adjacent to the liner. The same difficulty was observed in attempting to repair defects in stainless steel castings containing sulphur as a free-machining element. Frequently the undercut produced resulted in a "repair" which was worse than the original defect. In certain cases it was possible to obtain a good profile by the addition of filler rod, but with more difficult welds, the fitting illustrated being a case in point, undercut persisted and it became necessary to find some immediate remedy.

A series of casts of various types of stainless steel, each with and without the addition of sulphur, was made and the castings turned up to 1½ in. outside diameter × 14 s.w.g. tube, 1¾ in. long. These were mounted in turn on a rotating jig and welded to 14 s.w.g. titanium stabilised 18/8 tube of the same dimensions, using a stationary argon welding head and constant conditions of speed, current, arc length and gas flow. The results are shown in Table 4.

The samples containing sulphur were markedly worse than those without, whilst the most satisfactory weld was obtained with the 18/8+Ti. Subsequent experience has shown that in the case of selenium-bearing steels where the selenium is added instead of sulphur to give free-machining properties the same problem arises and can be traced to the addition of the free-cutting element. It therefore appeared fairly clear that the trouble was due to a highly fluid slag produced by the presence of substantial proportions of sulphur or selenium in the metal. An attempt was therefore made to thicken up this slag by the use of a welding flux. The experience of welding stainless steel sheet recorded above suggested

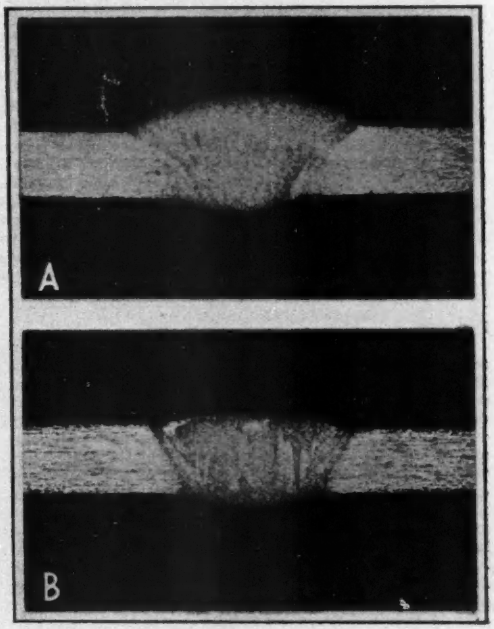

Fig. 1. Welds in 16 s.w.g. titanium-bearing 18/8 stainless steel. Sections × 7.
(a) Metallic arc weld.
(b) Argonarc weld, made with filler rod.

titanium or silicon as agents which could be used to this end. Titanium, however, had been proved ineffective by the tests on cast tube, and silicon remained as the most obvious choice. Various types of silica-bearing fluxes were tried out, and most satisfactory, although not the least expensive, proved to be a silicone rubber compound which contained a proportion of

Table 2

Steel	Weld	Welded Sample		Parent Metal		Weld Efficiency per cent.
		U.T.S. (tons per sq. in.)	Elongation per cent.	U.T.S. (tons per sq. in.)	Elongation per cent.	
A	Argon, without filler	44·7	31	46·9	45	95·0
A	Argon, with filler	45·8	33	—	—	97·5
A	Metallic arc	42·3	28	—	—	90·0
B	Argon, without filler	44·2	27	45·9	40	96·1
B	Argon, with filler	45·0	29	—	—	97·8
B	Metallic arc	42·4	25	—	—	92·5

titanium oxide as filler. This material combined the virtues of high silicon content, ease of application in a non-aqueous solution (the presence of water being fatal to success with argon welding) and low carbon content, thus avoiding the risk of carbon pick-up. Applied to the welded fitting which gave rise to the problem, this flux eliminated undercutting and enabled welding to proceed satisfactorily (Fig. 3).

Arc Wander

The second problem concerned the arc itself. It tended to flutter around the electrode immediately after striking and, having settled down at the tip, to wander slightly during the weld run, particularly when currents below 75 amps. were used. In practice, this was not so serious as to make the process unworkable; rather it hindered the rapid training of operators and the easy application of the torch to awkward welds and to work requiring filler rod.

A reasonably steady arc can normally be obtained from pure tungsten electrodes by using a rod of the minimum diameter required to carry the welding current and by keeping a sharply pointed tip. This does not, however, provide a complete answer to the problem, since in welding thin gauge material the optimum diameter of the rod is frequently 1/16 in. or 3/32 in. and electrodes of this size are extremely fragile. An attempt was therefore made to improve the character of the arc, so that heavier rods could be used, by increasing the thermionic emissivity of the electrode. Grounds for assuming that the arc characteristics could be changed in this way are given in the Appendix, where it is shown that the effect of using materials of higher emissivity should be to cause a fall in the operating temperature of the electrode and a reduced tendency to arc wander.

The first material tested was "thoriated" tungsten.* This is used in the radio industry to increase the efficiency of the cathodes of thermionic valves and it is known to have a markedly higher emissivity than pure tungsten. It consists of pure tungsten in which a small amount, in this case about 0·5 per cent., of thoria (ThO_2) has been incorporated, and it has been shown that its efficiency is due to the presence, on the tungsten surface, of a layer of thorium atoms. This surface layer has the effect of reducing the work function, and increasing the thermionic current density for any given temperature.

One-eighth inch electrodes of this material were tried out under practical welding conditions and a general improvement in the arc characteristics was immediately apparent. There was less tendency to wander, the arc appeared to be less bright and the electrode ran cooler. Several incidental advantages were also noted. Due possibly to the lower cathode temperature, there was less tendency for weld metal to be picked up by the tungsten, and it was therefore possible to weld for longer periods without regrinding. The electrode size also was less critical and $\frac{1}{8}$ in. diameter rods have been successfully used over a range 30 to 120 amps., thus simplifying the equipment required.

The second material to be tested was "oxide-coated" tungsten Again, this type of emitter, which consists of a base metal coated with a layer of one or more of the alkaline earth oxides, has found considerable use in the radio industry. It is more efficient than thoriated tungsten at low temperatures, but at the temperature of the arc cathode there is some doubt as to which would give the greatest electron emission.

In practice, tungsten coated with an alkaline earth oxide proved to have the same characteristics as thoriated tungsten when used as a welding electrode.

The use of both these types of electrode has been of considerable

Table 3

Steel	Solution	Results		
		Argonarc Weld without Filler	Argonarc Weld with Filler	Metallic Arc Weld
A	10 per cent. acetic acid + 2½ per cent. NaCl.	No activation or etching.	Very slight etching of weld metal. No activation of parent metal.	Weld metal etched. Parent metal slightly activated.
B	(*a*) 50 per cent. acetic acid + 2½ per cent. NaCl.	No activation or etching.	—	Weld metal etched. Parent metal slightly activated.
B	(*b*) 80 per cent. acetic acid + 2½ per cent. NaCl.	Weld metal etched, parent metal activated.	—	Weld metal etched. Parent metal activated.

Table 4

Cast	Analysis				Weld Profile
	C	S	Ti	Mo	
1a. 18/8	·06	·012	—	—	Slightly undercut at end of run.
1b. 18/8+Ti	·06	·012	·69	—	No undercut
2a. 18/8	·09	·02	—	—	Undercut at end of run
2b. 18/8+S	·09	·43	—	—	Undercut at edge
3a. 18/8	·075	·038	—	—	Undercut at end of run
3b. 18/8+Ti+S	·08	·47	·54	—	Undercut severely along edge for one-third of run
4a. 18/8+Mo	·075	·05	·05	3·23	Narrow line along edge at start
4b. 18·8+Ti+S+Mo	·075	·63	·60	3·15	Sever undercut

Ni nominal 8 per cent.
Cr „ 18 „

* British Patent Application No. 25710, 1947.

practical value, making it possible to produce neater welds and enabling the operators to maintain a steady arc with the minimum amount of regrinding of the electrode tip.

Production Tests

Having shown, by laboratory tests, that the quality of argonarc welds was rather higher than the previously accepted norm, it was decided to try it out in production, and to obtain, amongst other information, some measure of the cost as compared with metallic arc welding. Using a D.C. welding generator and a commercially-available hand torch it was applied to the fabrication of the small 16 s.w.g. stainless steel pot shown in Fig. 4. With the corrosion test results in mind, it was decided to make all welds without filler rod. Copper backing bars and light jigs were used for all welding operations, so that a light and consistent penetration was obtained on the underside, whilst the top side of the weld was flat. In order to obtain the good fit which was necessary for this type of weld, the bottoms were machined before making the circumferential joint. Otherwise no edge preparation was required.

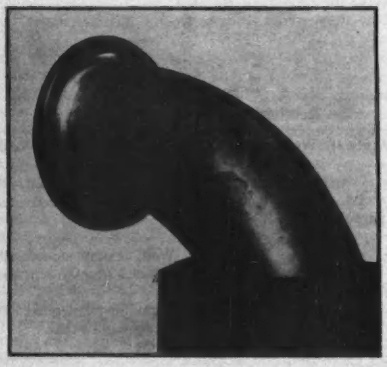

Fig. 2. Argonarc welded fitting. Weld between free-cutting stainless steel and titanium-bearing 18/8 tube, made with the addition of silicon flux.

The result was a pot of greatly improved external appearance, but some 4 per cent. more expensive to produce than its arc-welded predecessor. Argon gas costs were mainly responsible for this increase, combined with the additional expense involved in machining the bottoms; thus the advantage of argonarc welding in this case lay only in such imponderables as improved appearance, improved weld quality and a possible improvement in corrosion resistance. More immediate incentives were required to make the process applicable on any scale, and a considerable amount of effort was therefore expended to make it more economical and to reduce gas consumption.

There were four main lines of approach. The first was the application of argonarc welding to jobs where some additional economic advantage was obtained by its use, as for example in work where it was required to polish out the top side of the weld. In a substantial number of cases, which will not be described in this paper, it was found that such economies could more than offset the increased welding costs. The second was the use of more efficient gas economisers, the third the dilution of argon with less expensive gases, and the fourth the development of mechanical methods.

Gas Economisers

Two types of economiser were used at first—the switch incorporated in the handle of the torch and a standard type of gas economiser which is used for oxy-acetylene welding. Both of these devices, although fairly reliable in operation, inevitably depended upon the operator. It must be borne in mind here that accidental over-consumption of gas through leaving a bottle open and through operator wastage can quite substantially increase costs, and that some method of preventing such accidents must be found. Methods of automatically cutting off the gas after breaking the arc were therefore investigated and a relay circuit was developed which eliminated much of the wastage. This relay circuit operates in conjunction with a D.C. welding generator and functions as follows: Firstly, the electrode is touched to the work; this starts the flow of gas and, a few seconds later, cuts out a resistance in the field windings of the generator, which permits the generator voltage to rise. The arc can then be struck by the operator, and during welding the gas flow is maintained. As soon as the arc is broken the resistance is again introduced into the field winding of the generator and the generator voltage reduced to a small value. The gas continues to flow for a few seconds in order to allow the electrode to cool and then is cut out by a solenoid-operated valve.

In order to use this type of economiser it was necessary to develop a new technique in tacking up work: instead of breaking the arc after every tack the operator first made widely spaced tacks and then joined the sheet at intervals between these points without extinguishing the arc, a method which in the event proved quite efficient.

The instrument has proved to be most useful for work in the open shop, *i.e.* where the operator is not working at a bench and where he is not able to use a static gas economiser of the mechanical type. The relay unit, being mounted on the welding machine, is mobile, and effective no matter where the operator is working.

Gas Flow

Throughout this development work it was found that the design of the nozzle and the way in which the gas flowed around the electrode was of considerable importance. If the gas flow was not symmetrical, then the arc became unstable and a porous weld was likely to result. Unfortunately, it was not found possible to develop an experimental technique to investigate this problem, but by trial and error an optimum design of orifice for the particular conditions required for welding thin gauge stainless steel was produced. The type of torch in which this design was embodied is illustrated in Fig. 5; a number of these were constructed and have proved quite useful for light work, it being found that for currents up to 75 amps. a gas flow of 1½ litres per minute was sufficient for good welding.

Dilution of Argon with other Gases

It was thought that the addition of either hydrogen or nitrogen might make it possible to decrease the cost of gas, whilst maintaining an inert atmosphere round the arc. Nitrogen was tried first, but it was found that as little as 5 per cent. of the gas mixed with argon gave a porous weld, whilst the arc was very "wild." Attempts to dilute the gas in this way were therefore abandoned.

The addition of hydrogen to the argon was initially rather more promising. Various mixtures were tried, ranging from pure hydrogen to argon with about 0·1 per cent. of hydrogen, using a mechanical head and carriage with an automatic arc length control of the type to be described in a later section. To produce a stable arc with pure hydrogen, a high voltage generator is required, the arc voltage at normal arc lengths being of the order of 50V and the striking voltage being particularly high. In these trials, two normal D.C. welding machines were used in series to obtain the necessary open circuit voltage. It was found that with the electrode negative, the tungsten tip melted at any but the lowest currents and that the arc was extremely wild. The only way of avoiding this trouble was to maintain an arc length of the order ·005 in., which was only possible through the use of automatic arc length control. The weld thus produced on 14 s.w.g. sheet was remarkable in that its width on the top side was 2 mm. whilst the width of the penetration on the underside was 4·5 mm.

Such an arc, however, was very difficult to maintain and in every case the welds were porous. To avoid porosity, successively larger amounts of argon were added to the hydrogen in the hope that the remarkable penetration of the hydrogen weld could be combined with the soundness of an argon weld. It was found that the best results were obtained with a mixture of argon + 10 per cent. of hydrogen, but the welds were only free from porosity when

made in molybdenum-bearing steel using strictly controlled conditions of arc length, and without the addition of filler rod. A typical weld produced under these conditions is shown in Fig. 6. It is remarkably narrow, as compared with the equivalent argonarc or metallic arc weld, and the penetration is very consistent. It was decided, however, that the range of application was too limited for production work, particularly where the weld quality was all-important, and its further development was abandoned.

This does not exclude the possibility that such mixtures might prove very useful in particular applications, and in fact it has been used in making argonarc spot welds between stainless steel sheets. The technique of argonarc spot welding was developed in the U.S.A. as a method of pinning two sheets together. The arc is played on the surface of the top sheet for a few seconds, arc length and time being controlled, the former by a refractory spacer between the nozzle and the work and the latter by means of a weld timer. This produces a plug of weld metal penetrating through the two sheets. On stainless steel, the addition of 5 to 10 per cent. of hydrogen to the argon was found to give a deeper plug for a given size of spot on the top side than the corresponding argonarc weld. In addition to this, the profile of the spot is better, being slightly raised instead of slightly sunk away, and requires the minimum of grinding. Typical spot welds produced by a hydrogen/argon mixture, and by pure argon, are shown in Fig. 7.

Mechanical Welding

Mechanical welding, properly applied, has other virtues besides that of reducing gas costs. The welds are more consistent, there is less distortion, and labour costs are reduced. However, it has been found that, other things being equal, the saving in gas costs obtained by mechanisation (*i.e.* by increasing the welding speed) is, with the price of argon gas at its present level, a substantial proportion of the total saving. It is on these grounds that mechanisation has been considered here as a method of gas economy.

It is not proposed, in this section, to deal with the practical problems of applying mechanical argonarc welding to the fabrication of stainless steel vessels, but rather to describe some of the more interesting features of the welding head which has been developed.

The argon arc is peculiarly adapted to mechanical welding, since the electrode is not consumed, and the arc provides a steady, high-temperature heat source which makes possible high welding speeds and close control of the degree of penetration. In order to make the fullest use of these characteristics, it is important to maintain constant conditions during the weld run; consequently, it was necessary, in developing the welding head, to find a method of maintaining a fixed arc length. In welding straight seams in a substantial jig it was possible to avoid altogether any form of arc length control. However, the potential application of this methodfor the welding of circumferential seams, where it would not bepossible to guarantee perfect roundness, made it advisable to use some form of arc length control gear. For this purpose an electronic unit was developed, in conjunction with a well-known firm of electronic engineers, which has proved very efficient in production.

The problem of applying electrical control using the variation of voltage across the arc with arc length is rather more exacting than in most forms of welding, because the argon arc has a particularly low rate of change of voltage with arc length. A number of experiments were made using a water-cooled torch-head and a copper anode to determine the relationship between these quantities, and the curves shown in Fig. 8 are typical of the results. It is interesting to note that under these conditions, when both electrode and nozzle move together relative to the anode, the relationship is not quite a straight line and a flat portion appears on the curve between arc lengths of approximately ·015 and ·025 in. Fortunately, the arc length in this type of welding is not critical

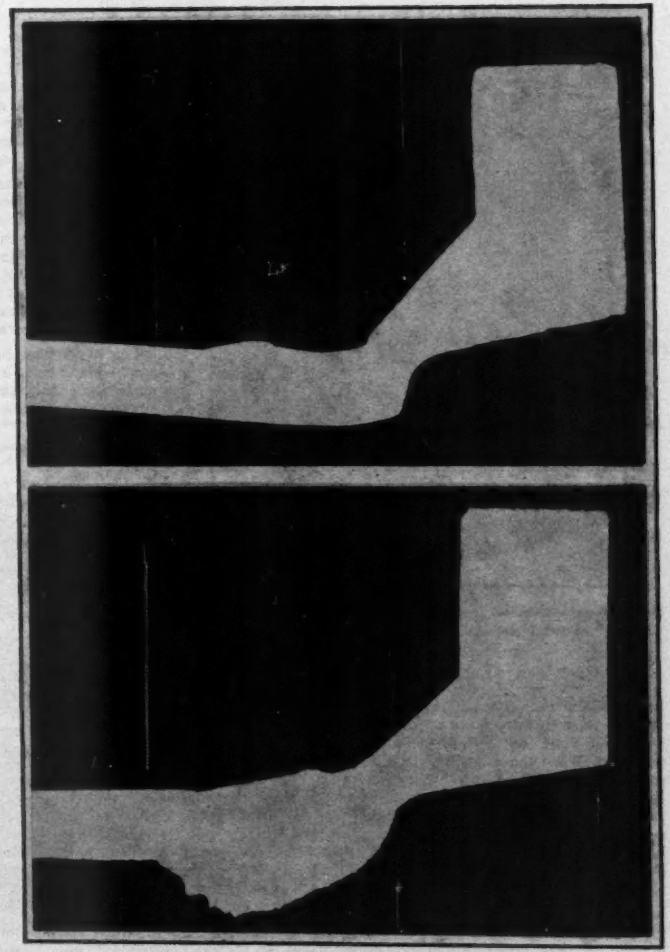

Fig. 3. Sections of the type of weld illustrated in Fig. 2, ×7.

(a) Without the use of flux. Showing undercut at the right-hand edge of the weld, adjacent to the machined liner. The underside of this weld has been ground flush with the tube.

(b) Showing the improved weld profile obtained by using a silicone flux. Underside of the weld has been left unground.

and it was therefore possible to operate within the region ·05 to 0·1 in. where the gradient is of the order 40V per inch.

It was decided that in order to obtain a sufficiently constant arc length, the control unit would have to operate with a limit of ±0·1V and, in fact, when it was finally produced the maximum sensitivity was ±0·05V. The principle of its operation has been used in automatic metallic arc welding. The welding head is moved up and down relative to the work by means of a small motor. This motor is controlled in such a way that when the arc voltage is greater than a pre-set value it drives the welding head down and when it is less than its pre-set value it drives the welding head up. A universal type shunt wound motor is used, the field is constantly excited and the direction of rotation depends upon the direction of current flowing through the armature. This armature current is supplied by either one of two thyratron valves, one providing current in a direction which drives the welding head up, and the other performing the opposite operation. The grids of these thyratrons are in turn controlled by the difference between the arc voltage and the pre-set fixed voltage suitably amplified. When the arc voltage exceeds this pre-set voltage by more than ·05V the "down" thyratron strikes and the welding head moves downwards; when the arc voltage is less than the pre-set voltage by the same amount the "up" thyratron strikes and the welding head rises. When the arc voltage is within ±·05V of the pre-set value, both valves fire, and the head is held in a fixed position. The unit as a whole is stabilised against variation of mains voltage and against hunting.

Fig. 4. Argonarc welded 6-gallon vessel in 16 s.w.g. stainless steel. As welded. Dimensions: 11⅛ ins. diameter × 17 in. deep.

This electronic control has proved very effective in operation; its accuracy being limited by the mechanical arrangement for moving the head rather than by the sensitivity of the electrical circuit. It has, moreover, been found that even in welding straight seams, the constant arc length gives more consistent results than would otherwise be possible.

Fig. 9 illustrates the welding head, which is mounted on a jig capable of holding cylinders in 20 to 14 s.w.g. stainless steel of lengths up to 3 ft. 6 in. In principle, the latter consists of two rigid holding down bars and a copper backing bar which is supported on a length of air hose mounted on a steel rail. The job is set up on the backing bar and the steel rail raised and clamped to fix the two edges in position under the holding down bar. Air pressure is then applied to the hose; this holds the work firmly in position and irons out any slight bend in the sheets.

The traverse machine consists of a standard oxy-acetylene cutting carriage on which are mounted the electrode head, the filler rod feed and the various controls. The addition of filler rod has been found essential for consistent work when polishing-out of the weld is required and, although some mechanical difficulties were experienced in the first stages of its production, it has subsequently been found that its use represents very little extra complication.

A relay unit is used to control the operation of the machine. This is triggered by means of a switch mounted in the handle of the hand mask used during welding. On depressing the switch, the argon flow starts; the electrode is lined up and placed at the start of the work, and the arc is then struck by means of a carbon rod. As soon as the arc strikes, the filler rod feed motor and the traverse motor of the carriage start up, and the arc length control gear is brought into operation. This automatically adjusts the arc to the correct length. On completion of the run, the operator switches off, motor and filler rod feed stop, and the arc is extinguished through the insertion of a resistance in the field winding of the welding generator. The argon continues to flow for 10 seconds in order to allow the electrode to cool without oxidation.

The speed of operation can be controlled, and is varied according to the type of job from 15 to 20 in. a minute. Whilst much greater speeds than this are possible, it was found that increasing beyond 20 in. a minute for short lengths gave little economic advantage, whilst at the same time making it more difficult for the operator to control; 18 s.w.g. filler rod is fed in at an angle of about 10 deg., so that it is in contact with the work whilst the machine is running along. The speed of the filler rod feed is kept constant; if additional reinforcement is required, heavier gauge wire is used.

Fig. 10 compares an average quality metallic arc weld, made by hand without using a jig or backing plate, with an argonarc weld made using this automatic arrangement; it demonstrates the advance in technique which the advent of argonarc welding has made possible.

Conclusions

It is hardly possible to summarise briefly the rather diverse matter which is presented in this paper. The following points, however, derive logically from the development work which has been described; it should be noted that they apply particularly to the welding of thin gauge austenitic stainless steels.

1. The quality of welds produced by the argonarc process is superior to those obtained using established methods.

2. The process, under present conditions (the price of argon gas being 1s. 6d. a cubic foot), is more expensive than metallic arc welding or oxy-acetylene welding, unless special advantages are obtained through its use (*e.g.* if polishing costs are reduced, or if the percentage of rejects is less, or if welds can be made from one side where previously double welding was required). Consequently, its field of application is still limited.

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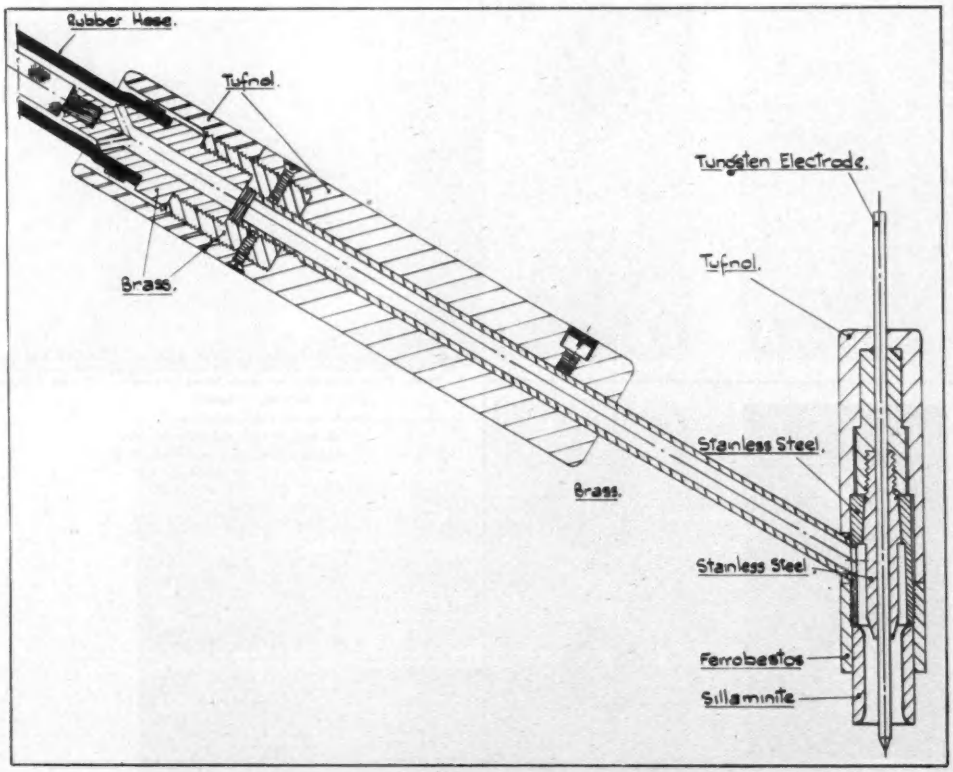


Fig. 5. Sectional elevation of argon arc welding torch. Scale: 2 : 3.

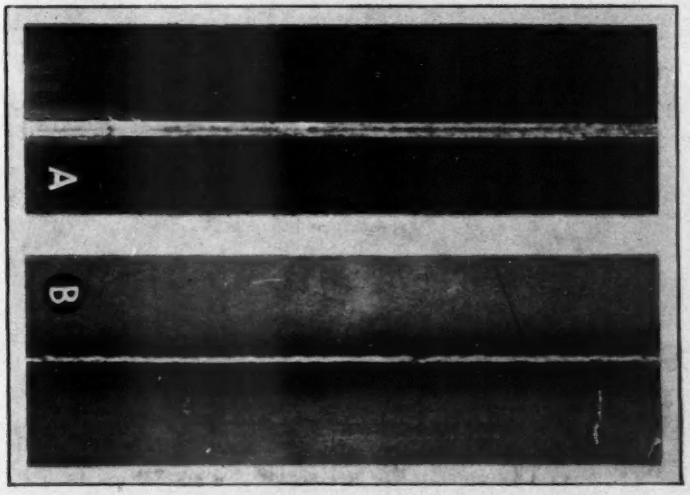


Fig. 6. Argon/hydrogen arc weld in 14 s.w.g. molybdenum-bearing stainless steel. Mechanical weld made without backing at a speed of 20 in. per minute. (Full size.)

(a) Topside.
(b) Underside.

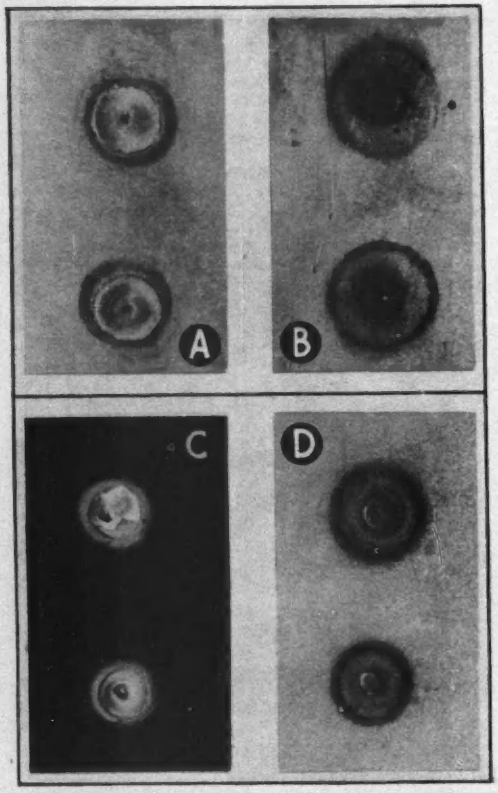


Fig. 7. Comparison between spotwelds made using commercially pure argon, and argon containing 10 per cent. hydrogen, in 14 s.w.g. stainless steel. Weld time approximately three seconds in each case (Full size.)

(a) [Argonarc weld: topside.
(b)[Argonarc weld: underside.
(c) Argon/hydrogen arc weld: topside.
(d) Argon/hydrogen arc weld: underside.

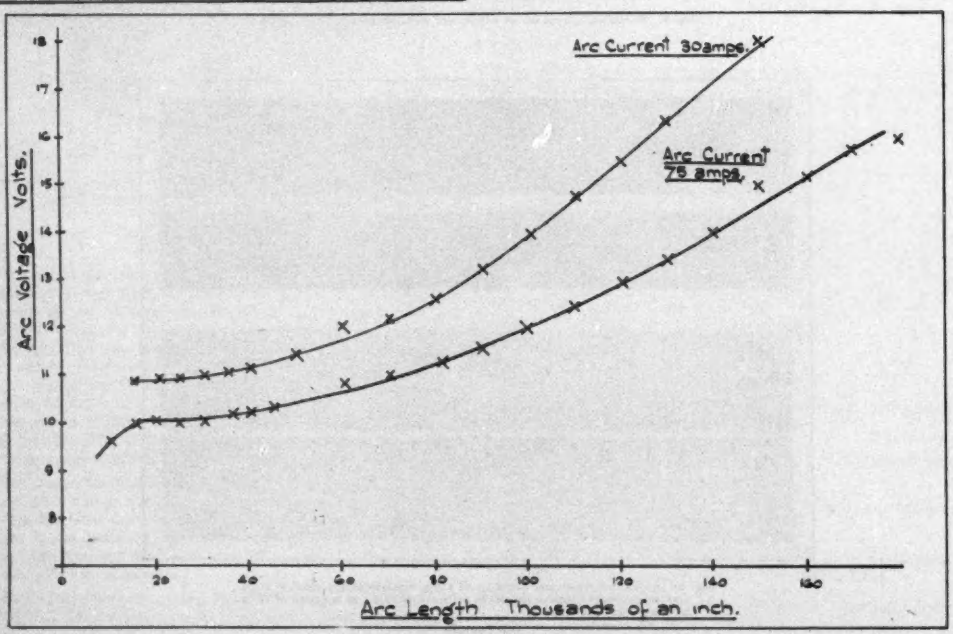


Fig. 8.—Voltage/Arc length. Tungsten-copper arc in 99 per cent. argon.

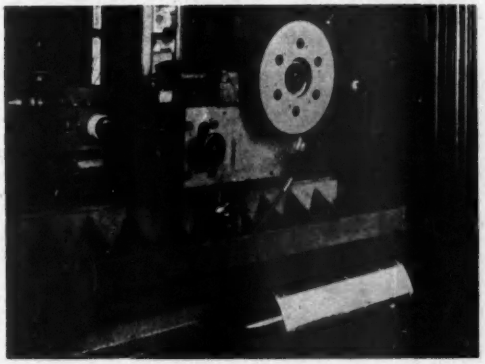
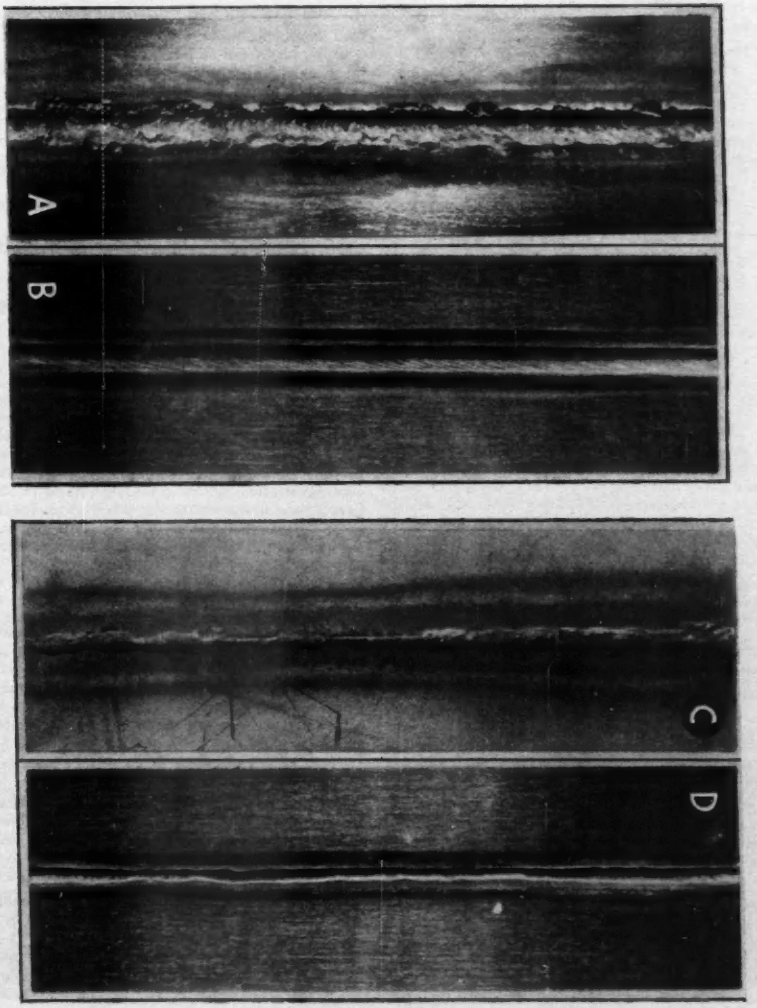


Fig. 9. Left. Automatic argonarc welding head, showing automatic arc length control mechanism and filler-rod feed.

Fig. 10. Below. Compares an average metallic arc weld with an automatic argonarc weld in 18 s.w.g. stainless steel. All as welded, full size.

(a) Metallic arc weld, topside.
(b) Automatic argonarc weld, topside.
(c) Metallic arc weld, underside.
(d) Automatic argonarc weld, underside.



APPENDIX

It is generally conceded that the normal D.C. arc between tungsten electrodes is thermionic in character; that is to say, that most of the electrons flowing from the cathode (in this case, the welding electrode) originate from a small area, the cathode spot, which is maintained at a temperature high enough to emit these particles thermionically. At the cathode spot an exchange of energy takes place; positively charged ions and neutral particles with high thermal velocities migrate to the electrode and here give up the energy which they have acquired, thus tending to increase the cathode temperature, whilst the emission of electrons, conduction of heat through the electrode, and radiation from its surface all tend to decrease its temperature. If the arc discharge is to be stable and self-maintaining, there must be a balance between these opposing tendencies and, roughly speaking, we can say that the greater the amount of heat transferred through the electrode by conduction and radiation for any given arc conditions, the greater must be the energy transferred to it by positively charged ions and neutral atoms, and consequently the greater the energy consumed in the arc.

Thus, it is logical that the cathode spot should form at the point where the heat flux is a minimum; *i.e.* at the point whence the heat loss by conduction is a minimum, which, in the case of a pointed electrode, is the extreme tip.

The form of the D.C. arc in commercial purity argon bears a definite relation to the position of the cathode spot. Normally, when the spot is stable at the tip, the luminous zone takes the form of a cone, with its base on the anode, and its axis in line with that of the electrode. Should the cathode spot form on the side of the conical tip, however, the arc takes a more elongated form and projects approximately at right angles to the tungsten surface.

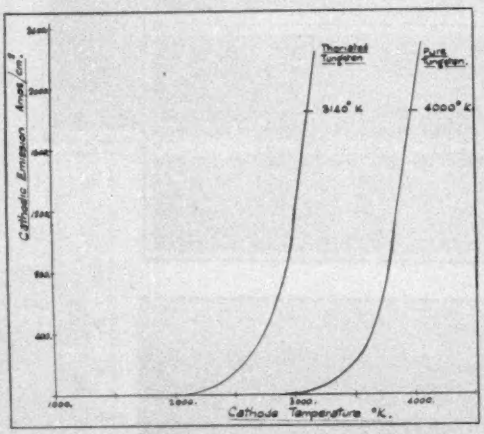


Fig. 1b.—Thermionic emission of pure and thoriated tungsten.

Consequently, movement of the cathode spot around the tip of a conical or spherical electrode causes a change in direction of the arc, to the detriment of efficient welding.

Using a pure tungsten rod, the establishment of a stable thermionic arc is associated with the formation of a small rounded area at the electrode tip. Closer examination shows that the tip has melted, and the area of the bead so formed corresponds roughly to the area of the cathode spot.

Two points of interest arise here. Firstly, the temperature required to produce the necessary thermionic current density must be close to the melting point of pure tungsten—3665 deg. K. Secondly, the fact that the cathode spot forms on molten metal reduces the probability that it will remain stable in one position—as may be shown by introducing a little hydrogen into the arc, when a substantial area of the electrode tip melts, and the arc becomes unsteady in proportion to the amount of metal melted.

It is therefore reasonable to suppose that material of greater thermionic emissivity, which could produce the same cathode current density at a temperature below the melting point, might permit the formation of a steadier arc.

Fig. 1b shows the relationship between saturated thermionic current density and temperature for pure and thoriated tungsten. These curves have been plotted using the equation for thermionic emissivity[6]:

$$\text{Log}_{10} J_S - 2\log_{10} T = \log_{10} A - \frac{b\theta}{2{\cdot}303T}$$

where J_S = emission current, amps./cm.²
A is the "temperature coefficient" of emission in amps./cm.²/°K.
T = temperature °K.
b = 11,600 θo.
θo = net work function of material in electron volts.

There is some uncertainty as to the actual temperature of the cathode spot. Measurements of the melted areas on electrode tips suggest an operating temperature between 3665 deg. K. and 4000 deg. K. For the sake of this argument, it will be assumed that the maximum operating temperature is 4000 deg. K.

It is reasonable to suppose that the cathode current density for thoriated tungsten has about the same value as that for pure tungsten, since this current density must be mainly a function of conditions in the cathode drop space, which remains substantially the same in either case. Hence, the probable maximum temperature of the cathode spot for thoriated tungsten is 3000 deg. K., which is below the melting point.

No attempt to derive the operating temperature of oxide-coated electrode is made, since values of A and θ vary widely with the method of forming the coating.[7] It would most probably, however, be lower than that for thoriated tungsten.

The experiment described below illustrates the difference in arc characteristics using these electrodes.

COMPARISON OF THORIATED AND PURE TUNGSTEN ELECTRODES

Experimental Arrangement

One-eighth inch diameter electrodes sharpened to give the same dimensions at the tip were mounted in a water-cooled head and suspended over a copper (non-melting) anode. Power was supplied by a motor generator set with an open circuit voltage of between 85V and 45V, depending on the current setting. The arc was struck by lowering the torch until the electrode tip touched the copper with the machine set for a welding current of 30 amps. The arc having been struck, the setting was then increased slowly in steps up to 70 amps., then finally reduced in steps again to 30 amps. Tungsten and thoriated tungsten electrodes were tested in this way.

Results

1. *Pure Tungsten*

The arc was initially unstable, the cathode spot travelling over the conical surface electrode, and the electrode appeared a very dull red through the welding screen. At 70 amps. the cathode spot stabilised at the tip, which became just molten. The electrode appeared bright red through the welding screen. On reducing the current the arc remained stable, but at 30 amps. showed considerable tendency to wander around the tip.

2. *Thoriated Tungsten*

The arc struck immediately at the tip, showing a bright cathode spot, the rest of the electrode being quite dark through the welding screen. At 70 amps. the arc was still stable and the electrode appeared a dull red. On reducing the current to 30 amps. again the arc showed a slight tendency to wander over a long period.

It will be seen that the use of thoriated electrodes permits easier striking at low currents. This advantage might be ascribed to the lower cathode temperature of this material as compared with pure tungsten on the grounds that less time is required to heat the tip to the emitting temperature. Without, however, analysing this idea in any detail it may be said that the difference in temperature

does not appear to be sufficient to account for the observed difference in striking characteristics, and an alternative explanation has therefore been considered.

Table 1a shows the first ionisation potential of the gases likely to be present in the arc. The voltage across this type of welding arc is commonly about 12V, so that ionisation of argon, oxygen

Table 1a

Element	First Ionisation Potential of Neutral Vapour. Volts [8, 9]
Argon	15·69
Nitrogen (atomic)	14·5
Oxygen (atomic)	13·56
Tungsten	8·10
Iron	7·8
Nickel	7·6
Molybdenum	7·35
Titanium	6·8
Copper	6·75
Thorium	5·7 [10]
Barium	5·18

or nitrogen is hardly possible, whilst the ionisation potentials of all the metallic vapours noted lie below the minimum recorded total arc voltage. It seems probable, on these grounds, that under welding conditions the ions form from metal vapours present in the arc atmosphere, and that the metal with the lowest ionisation potential will be preferentially ionised. Thus, in the case of thoriated tungsten, thorium vapour will be ionised; in the case of pure tungsten, either tungsten vapour or vapours emanating from the anode.

There are, therefore, two factors which may influence the striking characteristics of thoriated electrodes; firstly, the higher rate of evaporation of thorium at any given temperature, and, secondly, the lower ionisation potential of its vapour. For any given conditions of current, electrode geometry, etc., both these factors would tend to reduce the time required to establish a stable arc with thoriated, as compared with pure, tungsten.

From the discussion of arc characteristics two conclusions are drawn:

(1) that increasing the thermionic emissivity of tungsten electrodes by the use of surface-active agents such as thoria and barium oxide materially assists in producing a steadier arc;

(2) that the presence of a surface layer of a relatively volatile electro-positive metal on the surface of the tungsten has a beneficial effect on the ability to strike a steady arc.

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BOOK REVIEWS

Welding Handbook, 3rd ed., 1950. Publishers: American Welding Society, 33, West 39th Street, New York, 18. Price: 13 dollars outside the U.S.A. May be ordered through any technical bookseller in Great Britain. Price: £5 10s.

This well-known handbook gives comprehensive information on the welding and allied processes used in the joining of ferrous and non-ferrous metals. The relatively new processes, such as welding in inert atmospheres and cutting by the oxy-arc and flux injection methods, are included. On the other hand, no reference is made to the Elin-Hafergut process, first introduced in Stuttgart in 1939, on which papers have appeared in American periodicals as well as in those published in Europe. The chapter on pressure welding, using oxy-acetylene as the heating method, is excellent, but cold pressure welding, which originated in Great Britain, did not reach America until the Handbook was in the hands of the printer.

The section on welding and allied processes is followed by the application of welding to ferrous and non-ferrous metals, with full data on the properties of welded joints. There are chapters on cost estimating, welding metallurgy, physics of welding, welding terms, symbols, inspection, filler metal specifications, and testing by destructive and non-destructive methods. The sections on the application of welding to buildings, bridges, machinery, storage tanks, pressure vessels, ships, railway rolling stock, the automotive industry, and aircraft are profusely illustrated. Information on transmission pipe lines, a subject of increasing importance, is followed by a section on industrial piping.

The bibliographies appended to each chapter are mainly confined to papers in the *Welding Journal*, but as the most important articles in that periodical are usually followed by references to sources all over the world, their scope is wider than at first appears.

More than 300 tables are included, and the index of 65 pages, extensively cross-reference, is excellent. C. B.

Resistance Welding. By A. J. HIPPERSON and T. WATSON., 1950. Publishers: Iliffe & Sons Ltd. Price: 21s.

This book of 270 pages has been well conceived and will fill a definite need as a reference book for welding engineers, designers, factory executives, and anyone interested in the use of resistance welding. The book particularly emphasises the mass production possibilities associated with resistance welding processes; and quite rightly, as it is on such lines that the main economies and advantages over other assembly processes are to be obtained.

The authors have also achieved a praiseworthy blend of elementary and advanced information, suitable alike for students and for welding engineers responsible for the application and satisfactory performance of machines and requiring up-to-date technical information. The chapters on tooling for spot and projection welding are of particular interest and value, and some very interesting and instructive illustrations of various tooling set-ups are included.

Practical hints are given on the main dangers to avoid in the application of these processes, both in the design stage and in setting up a job for a production run. A chapter on hot riveting is likely to awaken interest in this somewhat unusual application of conventional spot and projection welding machines.

The layout of the book and the separation of all the recommended machine settings into a separate chapter, which could be rewritten and revised as further information on this subject becomes available, is to be commended.

It is unfortunate, however, that the book is marred by several typographical errors, one of which results in a misleading statement in the only detailed description of the operation of a control circuit. Until this mistake is appreciated by any reader who displays sufficient interest to follow through the description in detail, the function of this control circuit is unintelligible.

ELECTRICALLY WELDED TUBING ITS MANUFACTURE, PROPERTIES AND APPLICATIONS

By W. G. Clewlow, F.I.M.

The manufacture of tubing by Resistance Welding, which is the subject of this paper, to be read at the Spring Meeting of the Institute in Birmingham, is a striking example of the place held in modern industry by the welding processes. The author describes the methods used, the properties of the resulting welds and some of the numberless purposes for which such tubes are employed.

IT is commonplace to say that welding is playing an ever-increasing part in our industrial life. In no other field is this tendency more pronounced than in the manufacture of tubing, and so it may be profitable to examine some of the reasons for the tremendous developments which have taken place during the past twenty years.

HISTORICAL

Welded tubing is no new thing. The natural method of making a tube is to take a strip, fold it longitudinally and join together in some manner the abutting edges. This has been done from early times, and has given good results, considering the crude and primitive equipment employed.

The art of the blacksmith was used to produce a sound joint in wrought iron tubes and his process has been mechanised, to develop finally into the butt-welding process familiar for many years and still very largely used for producing gas, steam and water pipes in mild steel. This process, satisfactory though it may be for some purposes, has certain limitations with respect to (1) the sizes which may be conveniently produced, (2) the mechanical properties developed and (3) the surface finish obtained. As a result of this and in response to a growing demand for strong thin-walled tubes with a high degree of surface finish, the manufacture of seamless tubes made great strides. The demand was fostered by the growth of the cycle industry at the beginning of the century, and the improvements in boiler practice leading to higher temperatures and pressures, which in turn demanded more exacting tube requirements. Engineers became more aware of the advantages of tubular construction for many applications, but the high initial cost of seamless tube prevented its widespread employment. So by 1920 conditions were favourable for the introduction of a new process of tube welding—the Electric Resistance Process—which possessed several novel features.

By this process tubes could be made economically in a range of sizes and thicknesses unsuited to the older processes. They could have a surface finish, both inside and outside, as good as, or better than, the seamless competitor. And the weld could be made as strong as the parent metal but yet sufficiently ductile to permit drastic manipulation. This process made steady progress in the U.S.A., and in 1928 the rights were acquired in this country, a plant was installed and manufacture on a large scale commenced. A measure of the success of the process is the steady growth during the last twenty-two years in the output from this plant alone, which is now around 4,000,000 ft. per week, in sizes ranging from ¼ in. to 4½ ins. and thicknesses from ·030 in. to ·250 in.

The Process

The raw material is mild steel strip in coil form, the coils being as large as possible—5 cwts. to 20 cwts. It is cold rolled or hot rolled according to the requirements of the finished tube; if hot rolled it will need pickling or cleaning in some other manner. Since the economical running of the plant demands long unbroken runs, many coils are built up by end-welding to give a total coil weight of 5-10 tons. The end-welds are merely temporary and are cut out and discarded at a later stage. The end of the large coil is then entered into the welding machine.

The welding machine consists of the three main sections—forming, welding and sizing. As the strip enters the forming section it is first sheared to give the correct width with clean-cut edges and then proceeds through stands of rolls, maybe six or ten of them, which gradually fold it longitudinally to a U-shape and ultimately to the round-butted, open-joint tube. A guide fits in the open seam and directs the tube into the welding section, where, still embraced by forming rolls, it is straddled by a pair of conductor

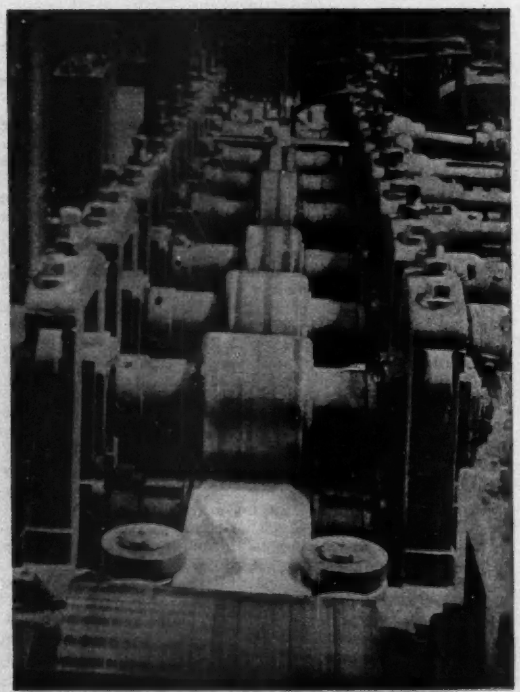

Fig. 1. Forming housing. General view

rolls or electrodes which are joined together mechanically but separated electrically. As the tube enters the welding throat, current is forced across the seam, instantly making the weld. Only a very narrow zone of metal is heated and the tube passes on, rapidly cooling, to have the outside burr or flash removed by a suitably mounted planing tool. When conditions permit, *e.g.* when the tube is of large diameter, the inside burr may be removed by a similar tool supported by a bar anchored in the forming housing. The process is now almost complete but the tube is not exactly round or straight. It is therefore cooled and passed through clusters of rolls which size it and straighten it. If section tubes are being made, further clusters of specially contoured rolls can be introduced here to give the desired shape. All that now remains is to pass on to a flying saw which grips the tube on its journey, cuts it off quickly and releases it so that the saw can return to make another cut at an interval of about 20 ft. The whole process, once started, is continuous, automatic and rapid, the tube leaving the machine at a speed of between 50 and 150 ft. per minute (Figs. 1, 2, 3 and 4).

The Process in more Detail

The success of the process depends on uniformity and accuracy, since the machine, once set up, must operate consistently for long periods. Raw material must be uniform in thickness, hardness and composition—its width is controlled by accurate setting and careful maintenance of the rotary slitting cutters. The forming rolls must retain their correct contours and their bearings must continue to run sweetly in spite of the heavy loads encountered.

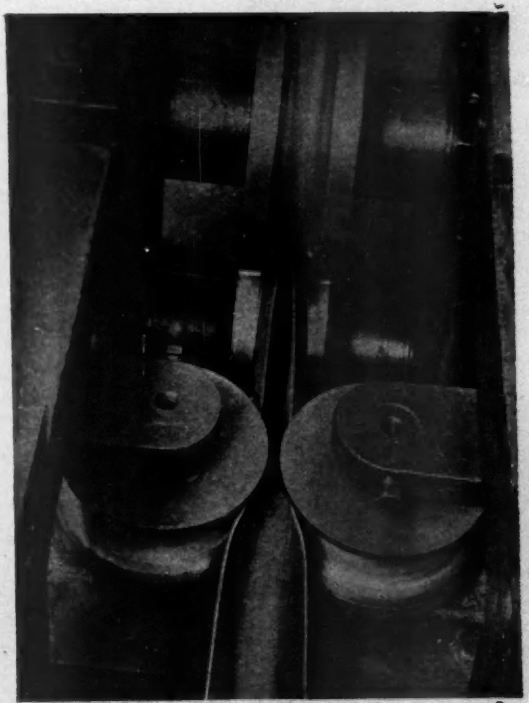

Fig. 1. Forming housing. Exit end

The seam guide must ensure that the joint is presented in the proper manner under the welding electrodes. The electrodes themselves must be of the correct contour and this is maintained by cutters which can rectify the profile while the machine is still running. Expansion, contraction and warping at this point are prevented by generous use of a coolant. The electrical energy supplied is set approximately correct for the size and gauge of tube being welded, and is in the range of 2 to 4 volts and 10,000 to 50,000 amps. Further vernier adjustments to this setting may be made by varying transformer tappings on the machine itself. The shape of the tube at the point of welding is also important, and this may be modified by raising or lowering the electrodes or adjusting the pressure on the welding rolls. Finally the speed of the tube is controlled at its optimum value, having due regard to all the circumstances, and this speed must be constant without any snatching or slipping. All this demands continuous vigilance on the part of operators and supervisors.

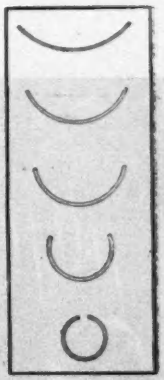

Fig. 3. Diagram of forming sequence

Testing

To ensure the quality of the weld, checks are made regularly while the machine is operating, a quick, simple test being the drift or cone test. A small sample is cut off and expanded over a tapered drift until failure occurs; the appearance of the split tube gives valuable information to the experienced Inspector, and any fault can be immediately corrected (Fig. 5). A more elaborate test which has the merit of testing a much longer length of welding is the hydraulic test, where a piece of tube some 30 in. long is pressure-tested to destruction, the bursting pressure required and the appearance of the failure giving very useful information.

Metallurgical Considerations

The object of the testing procedure outlined is to make sure that first-quality welding takes place and the strength of the weld is as good as, or better than, that of the parent metal. It may come as a surprise to some people to realise that this can be true, since there is no addition of metal or thickening in the welded zone. A short study of the structure of such welds should be interesting and help to make the reasons clear.

Microscopic examination of the cross section of a typical weld, at low power, will generally show a line at the junction and on either side a zone with a "spotty" appearance, not often observed

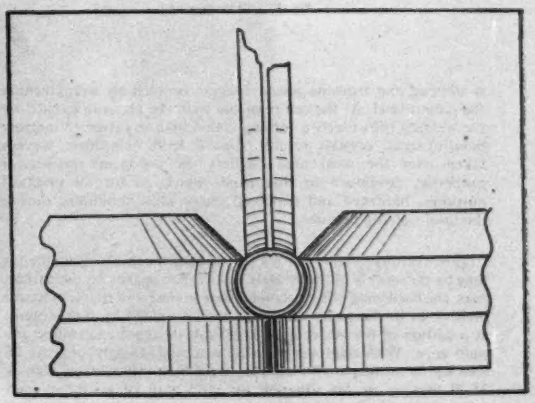

Fig. 4. Section at welding station

in other examples of welding and of such a nature that it may even suggest a local increase in carbon content (Fig. 6). More careful observation at higher magnification leads to a better understanding of what has happened. It must be remembered that the small area at the weld has been raised to a high temperature (1200 deg-1300 deg. C) and cooled back to about 500 deg-600 deg. C. in the space of only a fraction of a second. This short time is not enough to permit the usual changes which would occur in similar material if the heating and cooling cycle were lengthened a little. The result of this is that, before the carbide areas have time to be completely dissolved in the surrounding ferrite, the transformation

Fig. 5. Drift testing

is stopped and troostite areas remain, considerably strengthening the parent steel. At the centre of the weld the pressure applied by the welding rolls exerts a forging action and an extremely narrow band of small crystals results (Figs. 7, 8, 9). Hardness surveys taken over the weld area confirm the enhanced mechanical properties developed in that zone, which is, for all practical purposes, hardened and tempered under ideal conditions during the brief welding period.

This fortunate combination of circumstances is valuable as long as the steel is of moderately low carbon grade. As the carbon rises, the hardening effect becomes more intense and thus a practical limit is set to the steels which are readily welded by this process; at a carbon of 0·4 per cent. it is difficult to avoid cracking in the weld zone. With mild steels giving a tensile strength of, say, 26 tons/sq. in. in the parent metal, the weld-zone will reach as high as 28-30 tons/sq. in. So although the strip may be work-hardened appreciably during conversion into tube, the increase in strength at the weld is still sufficient to show a slight superiority and cause a tube to break away from the weld during testing.

American Investigations

This interesting phase of the metallographic aspects of resistance welded tubes has been dealt with very fully by Adelson in American literature* and will repay study. His summing up may be given here in full:—

"The ideal welded joint is one which is free from defects, one in which union has taken place between the original abutting surfaces, and one in which the microstructure has remained identical with the base metal.

No process has been developed to date which will yield a weld to meet these specifications, but it is believed that present-day electric resistance welded joints in low carbon tubing and pipe are the closest approach to it.

The joints, although slightly harder and of somewhat higher tensile strength than the base metal, still retain relatively high ductility and can be severely fabricated by hot or cold work without fracture.

The microstructural characteristics, when closely examined, undoubtedly offer ample proof of the properties which may be expected."

A very comprehensive series of physical tests was carried out in America by the Bureau of Standards in collaboration with Adelson,

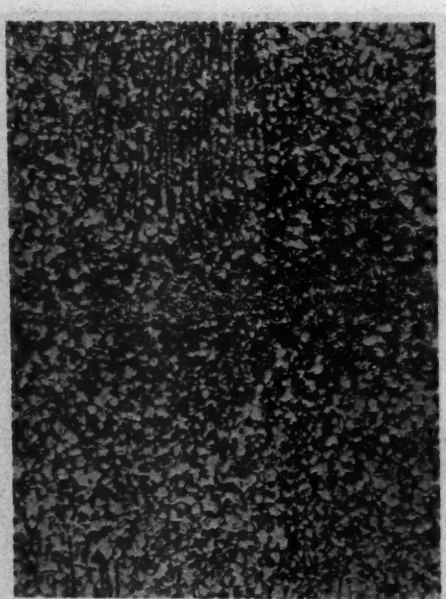

Fig. 6. Cross-section of weld × 75

and the results were reported in the *Journal* of the A.W.S. (Oct. 1930). These included tensile tests, crushing tests, torsion tests, hydrostatic tests, transverse tensile tests, hardness survey, flanging tests and microscopic examination.

Their conclusions are interesting, particularly as coming from

* *Metal Prog.*, Nov., 1932.

such an authoritative source. Examples are:—

"The average tensile strength of the circumferential strips cut from tube was practically the same as the longitudinal strength of the tube."

"The microscopic examination showed that there was no overheating or burning of the metal at the weld. The edges at the seam were heated to the welding temperature, and immediately forced together. Apparently there are no more inclusions at the weld than in the base metal."

"This investigation shows that the properties of the base metal can be used in determining the working stresses for different structural uses of tubing, no allowance being necessary for the altered structure in and adjacent to the weld."

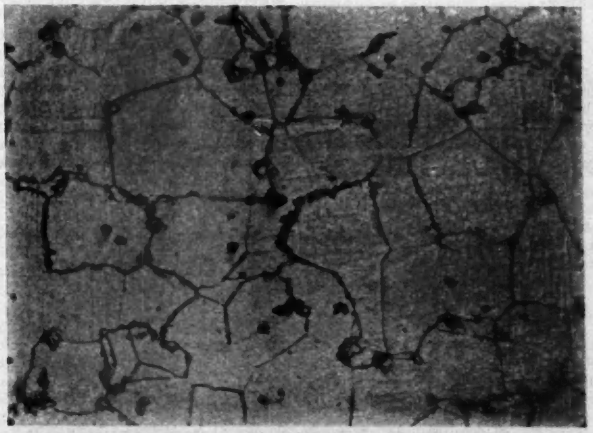

Fig. 7. Parent metal × 750

Annealing and Cold Working

In the condition in which it leaves the machine, the as-welded condition, the tube is quite strong but yet has sufficient ductility to permit of quite severe manipulation. It has a yield strength of, say, 15 tons/sq. in., a tensile strength of 25 tons/sq. in. and an elongation of about 25 per cent in 2 in. For very severe manipulation it may be necessary to resort to annealing, reducing the yield and tensile and raising the elongation to about 40 per cent. On the other hand, it may be desirable to produce a tube much stronger than in the as-welded condition. In this case the welded tube is quite able to undergo the drastic cold-working of the usual tube drawing operations, which can result in raising the tensile strength to about 35-40 tons/sq. in. These figures refer to steel with a carbon content of 0·10-0·15 per cent., the grade most commonly called for. Variations of the carbon to 0·15-0·20 per cent. and 0·25-0·30 per cent., combined with the three different conditions, viz. annealed, as-welded, and drawn, are capable of producing tubes with a wide range of mechanical properties well suited to most normal requirements.

The cold-drawing process applied to welded tubing has on occasions other advantages, sometimes for the maker, sometimes

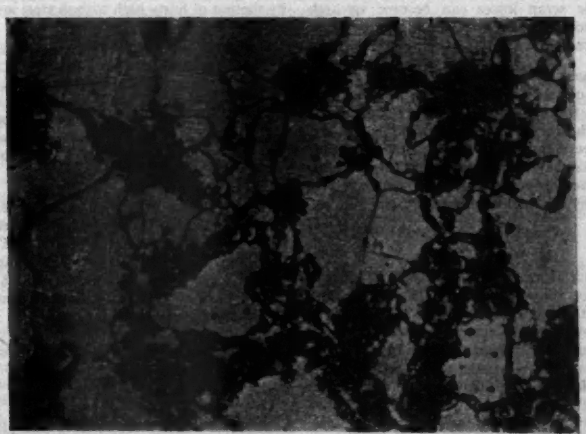

Fig. 8. Disturbed metal × 750

for the user. For example, it will readily be appreciated that there is a favourable diameter/thickness ratio of tube size—approximately 15 to 1—which is just right for forming and, when formed, is strong enough to resist collapsing under the electrode. Cold-drawing enables the "awkward" sizes to be produced economically. Again, short runs of odd sizes are wasteful of labour and material involved during setting-up. These, and special sections or special tolerances can all be produced by cold-drawing. An incidental advantage is that the cold-drawing process is a drastic proving-ground of the material—it has to be a good weld to stand up to the stretching and stressing involved.

Alloy Steels

The field covered by the range of welded tubing is seen to be a wide one, but could be much wider if it included alloy steels. Unfortunately the factors which tend to make the process attractive for mild steel work in the opposite direction when applied to alloy steels, particularly the high strength materials, which are prone to air-hardening to some degree. This does not mean that they cannot be welded—often they can—but the technique needs very critical adjustments and the scrap losses can become so high that until big demands for stock sizes are forthcoming, the process is not economically very attractive.

An alternative welding process, utilising part of the plant, may be employed with a good deal of success. The welding head may be removed and replaced by a fusion welding head, *e.g.* an atomic hydrogen torch, and with the much lower speeds employed the results are consistent, with less scrapping of valuable raw material. Austenitic stainless steels, Inconel, etc., are welded by this method, which shows undoubted economies in the case of some sizes which cannot be readily produced by the seamless tube industry.

Applications

The manufacture of tubing from strip carries with it several important advantages, the most outstanding being that the uniform gauge of the cross section of the strip ensures a perfectly concentric tube, or at any rate, a tube with a high degree of concentricity not easily obtained by other competitive tube-manufacturing processes. Another advantage is that, with the type of steel used and the methods of strip-rolling employed, a high degree of surface finish, both inside and outside, can be obtained; and the value of this is reflected in the enhanced ability to undergo severe manipulation.

These two properties, concentricity and good surface, are responsible for many widespread applications, and it may be interesting to consider a few of these in some detail.

Tubular articles which rotate at high speeds must be balanced to avoid vibration. Two good examples are (1) Automobile propellor shafts and (2) Vacuum cleaner rotors—the latter showing also an interesting manipulation operation in the central "neck."

Roller conveyors are usually mounted on bearings located in the bore of the tube. Eccentricity of any of the rollers gives rise to a bumping up and down movement, which spoils the smooth action often desirable for the conveying of certain classes of goods.

A more unusual but very important application is in the construction of rockets, or un-rotating projectiles. Here, although the tube does not rotate, uneven distribution of weight would lead to erratic and unpredictable path of flight. When the rocket is used as an anti-aircraft weapon and its flight is a long one, this factor becomes of prime importance. The rocket also demands a high degree of reliability, since internal pressures are high and burst welds must be avoided at all costs; in addition the tube must have a very high strength/weight ratio, a condition only made possible by the use of fairly high carbon steel in its hardest condition.

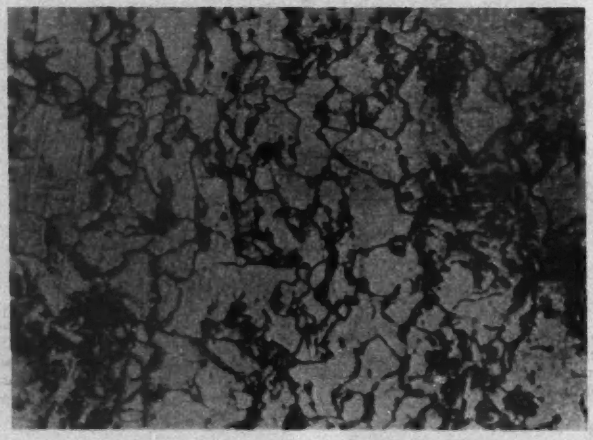

Fig. 9. Weld metal x 750

Common operations such as swelling or reducing tube ends are more satisfactorily carried out when tubes are concentric, and there is the general advantage in that eccentric weight, whilst it has to be paid for, does not carry with it any compensation either in increased strength or life under corrosive conditions. Machined tubular components are frequently "chucked" from the outside and turned or screwed inside. Here concentricity has an obvious advantage.

A high degree of surface finish is desirable for any application where enamelling and plating are called for. Bicycle construction is the outstanding example in this field and it is responsible for a very large share of the welded tube output. Not only does it cover the obvious—frame tubes, seat pillars and handlebars—but the less obvious such as front forks, manipulated stays, three-speed hub shells and even bottom brackets.

Perambulators, lawn mowers, saw-frames and ironing-board tables are other familiar examples of severely manipulated and highly finished tubes.

Welded tube has a large part to play in the production of electrical generating equipment. Air heater tubes and transformer cooling tubes—both round and oval—are required in large

quantities. The latter must be capable of holding warm transformer oil, even after considerable manipulation. A modern power-station also needs much hand-railing, especially around stairways where space is restricted. The welded tube, with its smooth surface and ability to be shaped around reversing stairways, is being used in increasing quantities.

Welded boiler tubes have been used in America for many years and are now regarded as nothing unusual. In this country perhaps prejudice is harder to break down and so far there has been no real demand for them. However, a British Standard covering electricially welded boiler tubes will shortly be issued, and trials on such tubes are already in hand by important users.

Anyone seeing the process in operation for the first time cannot fail to be impressed by the speed which enables vast quantities of any particular size to be produced at short notice and in a short time. This feature was of particular importance during the war and the crisis preceding the war, when there was a sudden unforeseen demand for some special article. Tubular stretchers may be quoted as a good example, the welded tube being strong enough to meet Home Office requirements, yet ductile enough to permit manipulation of the legs and side members from a single tube. This rush job was followed at intervals by others as the war entered different phases. Evacuation brought a demand for folding cots and beds. Camouflage schemes, the sten gun, ammunition of new type, Jerricans and Mulberry Harbour—all these needed astounding quantities of tubes—and always urgency was the order of the day. The ability to turn out, day after day, the hundred and one different jobs as they were required, was certain a tremendous asset to our harassed war industry.

So far most of the manipulation considered has been carried out in the cold; hot working considerably enlarges the field of applications. Tubes of larger diameter and heavier walls are frequently hot-forged, upset or flanged to make axles, etc. A very interesting example is the banjo axle formed by reduction at the ends and expansion at the centre. Here again concentricity proves its value, because of the absence of any tendency to thin down irregularly and so cause an unduly high amount of scrap losses.

Alloy Steel Tubes

Considerations of an economic rather than of a technical nature have prevented the widespread use of welded alloy steel tubes, through there are obvious difficulties in welding steels with air-hardening tendencies at high speeds involving very rapid heating and cooling. However, large demands for standard sizes could easily alter the balance and, in fact, large scale manufacture of Cr-Mo. tube of aircraft quality was undertaken in America during the war. Today welded Inconel and stainless steel tubes are being used for a variety of purposes, one of the most interesting being the manufacture of tubular heating elements for electric cookers.

Additional Processing

The high output of the modern welding machine sets a challenge to the ingenuity of the planning engineers, responsible for the additional operations after the primary one of tube manufacture. Provision on a generous scale must be made for annealing, cutting, testing, packing and transporting. Tubing, for its weight, occupies a good deal of space and unless careful and methodical removal of the tube is arranged for, chaos can quickly result. Lack of attention to such matters could easily outweigh the economies of the process and such aids to inspection as automatic hydraulic testing gear, to quote one example, all play an important part and are reflected in the price of the finished product.

The Future

Enough has been said to show that great strides have been made in the past, but it is also certain that welded tube will have a still bigger part to play in the future. A high degree of automatic and continuous operation has already been reached, but this will, no doubt, be pushed still further. Continuous casting and induction heating are still in their infancy, but we can look forward to the time when steel will be melted, cast continuously into strip, rolled, annealed, cleaned, and welded into tube, all in one electronically-controlled, perfectly co-ordinated process, the description of which may well be of interest to some future generation of the Institute of Welding.

Latest Additions to the Library

As a supplement to the Library catalogue, this section of the *Transactions* contains particulars of books and pamphlets added to the Library during the first quarter of this year. The books, pamphlets and periodicals specified are available on loan to members of the Institute.

Publications preceded by an asterisk are donations to the Library from authors or publishers; those preceded by a dagger are donated by the James F. Lincoln Arc Welding Foundation.

***ALUMINIUM DEVELOPMENT ASSOCIATION**

British standard nomenclature: aluminium and aluminium alloys for general engineering purposes related to other British specifications. (Chart.) 1950. Publishers: Aluminium Development Association, 33, Grosvenor Street, London, W.1. Distributed free on application.

AMERICAN PETROLEUM INSTITUTE

API specification for welded oil-storage tanks. API STD. 12C, of Sept., 1948, with supplement 1 of Dec., 1949. Illus. 1948-1949. Publishers: American Petroleum Institute, Dallas, Texas. Price: 1 dollar, 25 cents. (For sale at the British Standards Institution, 24/28 Victoria Street, London, S.W.1. Price: 9/-.)

***AMERICAN WELDING SOCIETY**

(a) (C.1.1-50.) Recommended practices for resistance welding. (a) (D.8.3-50T.) Recommended practices for salvaging automotive gray iron castings by welding. (Methods used in automotive repairs, including gas and arc welding, brazing, soldering, metallizing and mechanical means; typical defects and repairs being illustrated.) Publishers: American Welding Society, 33, West 39th Street, New York, 18. Price: (a) 1 dollar; (b) 50 cents.

***ARCOS CORPORATION**

The ABC's of welding high tensile steels. 7 pp. 1950. (Data on low hydrogen electrodes, coating types, applications, preheat and stress relief.) Publishers: Arcos Corporation, 1500 South 50th Street, Philadelphia 43.

BRITISH STANDARDS INSTITUTION

(a) Addendum to 1949 year book. 1950. **(b) (No. 1654-1950). Electrically welded mild steel boiler and superheater tubes.** Publishers: British Standards Institution, 24/28, Victoria Street, London, S.W.1. Price: (a) and (b) 2/-.

***CHARTERED MARINE ENGINEER**

Vol. 1, no. 1, April, 1950, *to date*. Publishers: Institute of Marine Engineers, 85, Minories, London, E.C.3.

***COKER, A. J. (Editor)**

Arc welder's tables and data. Illus. 1950. (A pocket book for the arc welder with data on equipment, electrodes and their classification. The procedure for welding mild steel, cast iron, stainless steels and non-ferrous metals is given. Cutting with the electric arc is included.) Publishers: George Newnes Ltd., Tower House, Southampton Street, London, W.C.2. Price: 5/-.

(*Continued on page* 130)

DISCUSSION ON "THE CONTROL OF DISTORTION"

By R. G. BRAITHWAITE, M.I.C.E.

Published in *Transactions*, Vol. 13, No. 2 (April, 1950)

MR. SILVERWOOD (Philips Electrical Ltd.) said that the methods adopted by Mr. Braithwaite for the control of distortion were very useful, and he quoted instances from his war-time experience of the manner in which distortion was controlled by completely unorthodox methods. One case concerned the fabrication of small high octane tanks for the Air Ministry. These tanks were approximately 5 ft. in height and 3 ft. 6 in. in diameter, and were made up from two small steel plates ¼ in. in thickness rolled to form a cylinder and butt-welded in the downhand position (Fig. 1). The two circular ends were then tacked into position and welded with 10-gauge electrodes. Owing to the fact that the job was being welded on a piece-rate basis, it was not difficult to imagine that there was a certain amount of

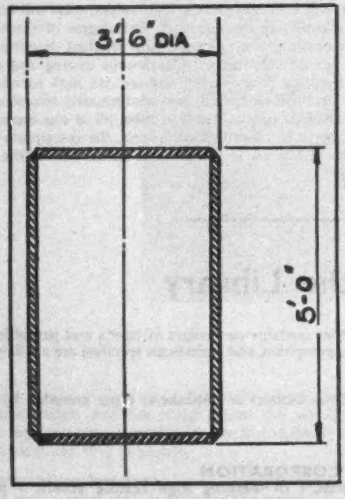

FIG 1.

distortion in the two ends of the tank. This distortion usually took the form of a concave "dish," the depth of which was anything up to 3 in. Several methods were tried to overcome this propensity to distortion and most of the text-book remedies were employed without result (Fig. 2).

The supervisor on the job, whose imagination was something out of the ordinary, thought up the idea of putting down spirals of weld metal, starting from the centre of the dished end and working outward towards the outer circumference. The speed of welding, and therefore the total heat-input to the distorted plates, naturally varied according to the extent of the distortion, but was determined by trial and error (Fig. 3). A boy stood by with a bucket of cold water which he threw onto the job immediately the arc was broken. The combination of the introduced heat and the sudden quenching had the desired effect, and the ends became perfectly flat within a matter of minutes (Fig. 4). Quite obviously the Air Ministry would have taken strong exception to the weld

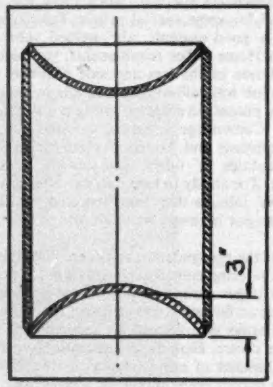

FIG 2

metal being left on the exterior of the job, and so it was a very simple matter to assuage their fears by making judicious use of an air-operated chipping hammer.

Another example, using similar principles, was the welding up of 60-ft. long girders for H.M.S. *Mauritius*. These girders were made up of mild steel plates ¼ in. thick, 60 ft. long by 9 in. wide, and there were three such plates to each girder. One flange plate was

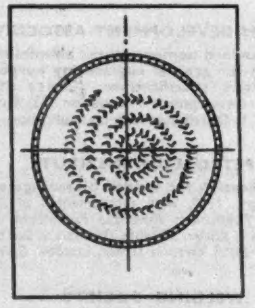

FIG 3.

secured to the jigging-down table and the web plate was tacked into position. These two were then temporarily tacked and the resultant fabrication was then lowered upside down on to the other flange.

Four welders commenced operations at the centre of the job, working away from one another towards the ends. It was soon discovered that the job was taking on a perfect rainbow contour. Several means were tried to circumvent the distortion in these girders, and it was not until it was decided to employ a method already recommended by Mr. Braithwaite in his paper that success was achieved. The method Mr. Silverwood referred to is, of course, that which involves setting up the plates in such a way that there is a "bridge piece" underneath the centre of the girder so as to give a pre-camber to the job; this means that as the job was cooling, the camber originally set into it would be automatically counteracted by the contracted weld-metal and the girder finished perfectly straight.

Mr. R. G. Burt (British Welding Research Association) suggested that in considering the control of distortion more attention should be paid to the use of the correct preparation and good fit up. It was more or less axiomatic that the less metal deposited the less the distortion and the use of the correct preparation and a good fit up not only reduced the amount of metal to be deposited, thus reducing welding costs, but also reduced distortion. In spite of this, one found it difficult to convince those responsible for production that time spent on the correct preparation and a good fit up really paid. One saw all too often bad fit ups being dealt with by quick bridging electrodes, but by doing so, in trying to overcome one defect, increased distortion, cracking and other troubles were introduced.

As an example of a preparation which reduced the amount of metal to be deposited and also assisted in reducing distortion, Mr. Burt referred to the "Double Vee, Close Butt Root Face" preparation. He pointed out that gaps were difficult to control, and variations led to variable quality of the weld and variable distortion. Even if steel wedges were used, these crushed down under the contraction forces and were difficult to extract. Welders sometimes cut these off and welded over them. Also, with a gap, chipping out the root was really necessary. On the other hand, using the "Close Butt Root Face" preparation and making the root runs with deep penetration electrodes the difficulty of controlling the gap was eliminated, less weld metal had to be deposited, distortion was less and chipping out the root of the first run was unnecessary provided suitable electrodes were used and care taken to ensure interpenetration of the root runs."

Mr. G. Roberts (Freeman, Fox & Partners) commented that the angular distortion of flange plates of welded plate girders could be one of the most troublesome distortion problems, but in his experience it could be avoided by the adoption of a simple rule in determining the relation between the width of flange w, the size of the fillets connecting it to the web s, and the thickness of the flange t. It is found in practice that if $\frac{1}{4}$ in. fillets are applied on a plate 1 in. thick and 12 in. wide, the distortion is negligible, or at least inconspicuous. Assuming that the edge deflection is proportional to the fillet size, and the width of flange, and inversely to the flange thickness, it may be expressed as a function of

$$\frac{sw}{t} = \frac{5 \times 12}{16 \times 1} = 3{\cdot}75.$$

If the flange dimensions and fillet sizes comply with this rule the angular distortion will be negligible. Frequently it will be found that compliance with the rule can be obtained by a small alteration to the width and thickness of the plate, without any detriment to the design.

An aspect of distortion control that the author had not dealt with was the difference in effect according to the order of welding. For instance, the curvature in a member caused by applying a line of welding to one edge will require approximately twice the amount of welding applied to the opposite edge to eliminate it. This procedure can be utilised in controlling the straightness in a vertical plane of members such as welded crane girders, which may have twice as much longitudinal welding on their top flanges as on the bottom flange. In such cases the bottom flange-to-web welding should be done first to give the girder an initial upward camber. The greater amount of welding applied to the top flange will then pull the girder straight.

Mr. A. G. Thompson (The Quasi-Arc Company Ltd.) said it was interesting to note that to obtain a flat and square flange plate in a flange-to-web connection, it was necessary to pre-set a flange plate, as shown in Fig. 3 of the paper, by only half the amount of the distortion that would occur if the plate were not pre-set.

Mr. Gilbert Roberts in this discussion also pointed out that to obtain a straight, built-up girder, the amount of welding on the second flange of a girder to be welded should be twice that on the first flange. Mr. Roberts showed an example where there were two runs of welding on one flange and four runs on the opposite flange.

These facts confirmed the soundness of a method of welding used to reduce distortion commonly known as "doubling up." In this method, a weld of given length is deposited on one side of a joint or member, and a weld of twice this length is then deposited on the opposite side. The speaker had seen several instances of this method being used with full success on plate girder work.

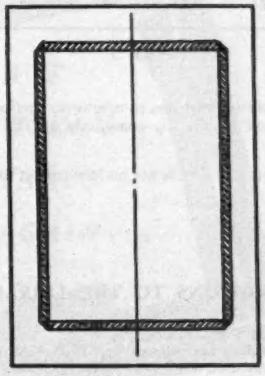

FIG 4.

Mr. Thompson then asked Mr. Braithwaite whether he favoured welding stiffeners to a plate girder during or after making the web-to-flange welds. In other words, a centre section of the girder might first be welded, followed by the welding of the central stiffeners; a further section of girder would then be welded and followed by welding two further stiffeners symmetrically placed about the centre line and so on. On the other hand, the complete web-to-flange welds may first be completed and the stiffeners then subsequently welded.

Mr. Thompson subsequently put forward the following suggestion, in writing, to overcome the chief disadvantage of the "doubling-up" procedure which is that it is not possible generally to complete a joint having equal weld lengths on either side by adhering strictly to this principle. After distortions have been balanced by this procedure a further length of weld remains to be made which causes distortion.

A weld of given length x is first deposited at the centre line of the joint on one side. A length of weld ($3x$) is then deposited at the centre of the opposite side of the joint; the length $2x$ counteracts the distortion due to the length x made on the first side, while the extra length x induces a distortion. This distortion due to extra length x on the second side is opposed by making two welds of length x either side of the centre line on the first side. The total length of weld made on each side of the joint is therefore equal to $3x$.

A practical example (Fig. 5) illustrates this procedure. A similar

procedure may, of course, be applied to the top and bottom flange-to-web welds of a plate girder.

Mr. A. C. Hart (Airspeed Ltd.) said that having listened to an extremely interesting and enlightening paper he was very disappointed to find that it was confined to plate and girder work.

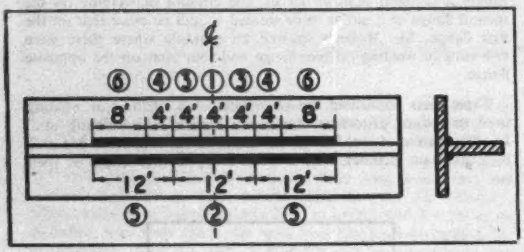

FIG 5

How did one control distortion in tubework, particularly the type of work common in aircraft, comprising 14, 17 and 20-gauge tubing?

Mr. Braithwaite said that he got his jobs correct to within $\frac{1}{16}$ in., whereas he (Mr. Hart) had to work to within thousandths, and though it might be comparatively easy to pre-set a plate or girder, he thought that the pre-setting of tubes would present considerable difficulties.

Continuing, Mr. Hart said that it was possible successfully to correct distortion dimensionally, but what the resultant stresses were he did not know, and in any case prevention was better than cure; he therefore concluded by asking if Mr. Braithwaite had any ideas on controlling distortion in tubework, since he for one would be more than interested to learn of them.

Mr. W. K. B. Marshall (The A.P.V. Co. Ltd.) said that it was impossible to discuss the subject of the preventing of distortion without referring to residual stresses. Clearly the particular method used for combating distortion would affect the sort of residual stresses left in the structure, and since the residual stresses were known to affect the performance of the structure at least in the elastic range, he would like to know whether Mr. Braithwaite had found any difference between structures in which the distortion had been prevented in different ways. For instance, he could imagine cases where a certain system of residual stress might be an advantage in giving increased stiffness, whereas other systems of residual stress might reduce the stiffness in the structure.

LATEST ADDITIONS TO THE LIBRARY—(*continued from page* 127)

GILL, E. T., and SIMONS, E. N.
Modern welding technique. Illus. 1950. Publishers: Sir Isaac Pitman & Sons Ltd., 39, Parker Street, London, W.C.2. Price: 21/-.

HILTON, B. R.
Welding design and processes. Illus. 1950. Publishers: Chapman & Hall Ltd., 37, Essex Street, London, W.C.2. Price: 36/-.

***IRON AND STEEL DIRECTORY AND HANDBOOK**
6th edition, 1950. (Contains lists of British manufacturers of pig iron and steel, blast furnaces, steel works, iron and steel groups, associations of iron and steel trades, and scientific and technical institutions. A section is devoted to conversion tables, abstracts of B.S.S. dealing with ferrous metals, and D.T.D. specifications.) Publishers: Louis Cassier Co. Ltd., Dorset House, Stamford Street, London, S.E.1. Price: 25/-.

***LAWTON, V. H.**
Examples of structural steel design to conform with the requirements of British Standard 499-1948. Illus. *British Construction Steelwork Association, Publication No. 1-1950.* (This brochure is intended to assist designers to take full advantage of the latest British standard on the use of structural steel in building. The changes are mainly due to revised superimposed loads, in particular, wind pressures and their distribution on buildings; increased working stresses using steels having a guaranteed yield stress; and revised methods of dealing with the combination of bending and axial compression, the lateral stability of beams, and the strength of girder webs for simple shear and combined bending and shear. The examples worked out by the author include a single storey building 50 ft. span by 150 ft. long by 16 ft. to eaves, and a single storey building 150 ft. wide (three 50 ft. spans) by 150 ft. long by 16 ft. to eaves.) Publishers: British Constructional Steelwork Association, Artillery House, Artillery Row, London, S.W.1.

***TIN RESEARCH INSTITUTE**
Report on the work of the Tin Research Institute, 1949. 1950. Publishers: Tin Research Institute, Fraser Road, Greenford, Middlesex.

TRADE CATALOGUES

JOHNSON, MATTHEY & CO. LTD.
(1) Sil-Fos silver brazing alloy. 1946. **(2) Silver brazing alloys.** 1949. **(3) Easy-Flo silver brazing alloy.** 1949. Address: 73/83, Hatton Garden, London, E.C.1.

KODAK LTD.
(1) Gamma radiography; data sheet. (2) Gamma radiography equipment assembly. Illus. 1950. Address: Kingsway, London, W.C.2.

METAL AND THERMIT CORPORATION
(1) A.C. arc welders. (2) D.C. arc welders, compact, portable, light-duty, single-operator 3500 r.p.m. (3) D.C. arc welders, single-operator, 150, 200, 300 and 400 amp. 1950. Address: 120, Broadway, New York, 5.

QUASI-ARC CO. LTD.
(1) The Quasi-Arc Mirroid (New Type) electrode (depositing Monel weld metal with corrosion resistant properties equal to those of the parent metal). (2) The Quasi-Arc pressure vessel electrode. Illus. 1950. Address: Bilston, Staffordshire.

DONALD ROSS AND PARTNERS LTD.
New jig speeds welding set-ups. Illus. 1950. Address: 1-3, Arlington Road, London, N.W.1.

H. TINSLEY & CO. LTD.
Tinsley resistance strain gauges. Illus. 1949. Address: Werndee Hall, South Norwood, London, S.E.25.

HENRY WIGGIN & CO. LTD.
Nickel alloy spring materials. Illus. 1950. Address: Wiggin Street, Birmingham, 16.

A. S. YOUNG AND CO. LTD.
(1) Corrosion tests on Colmonoy alloys. (2) Spraywelding Colmonoy on various metals. Colmonoy No. 6 brazing powder. Address: Tower House, Woodside Lane, London, N.12.

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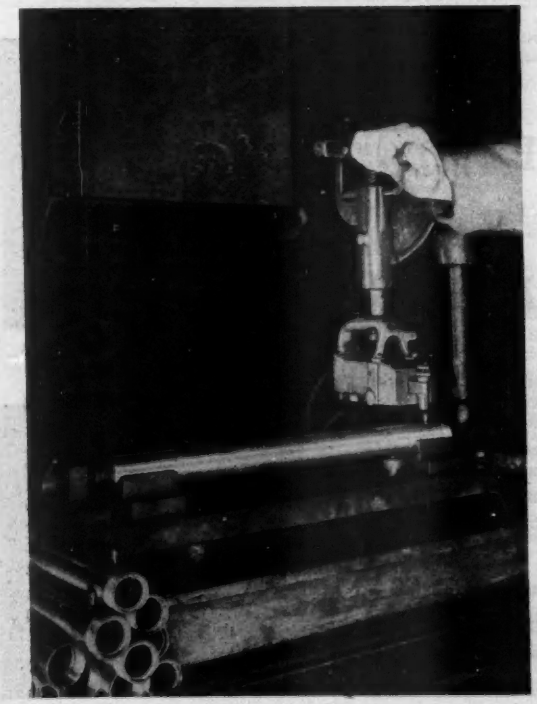

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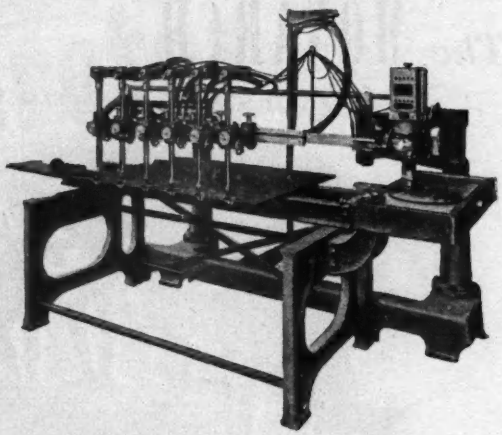

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(a) *A Ship's fractured Stern frame with a gap cut ready for a Thermit Weld.*

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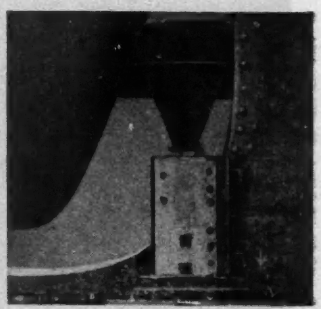
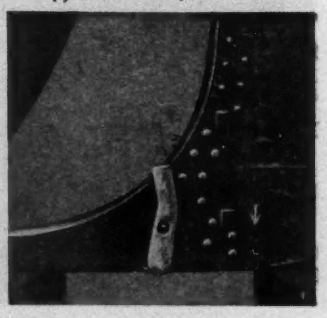


(b) *Mould box and crucible in position.*

(c) *Shows the completed weld.*



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Association Notes

"The Welding of Thick Aluminium Alloy Plates by the Argon Arc Process"

Argon arc welding equipment designed for operation with welding currents up to 600 amps. has been developed, together with suitable electrically controlled manipulating gear to enable mechanical (automatic) welding of longitudinal and circumferential seams. Welding technique for A.W.10 alloy has been developed to produce welds in plate up to $\frac{1}{2}$ in. thick which, after heat-treatment, give tensile properties equal to those of the parent plate, apart from a reduced percentage elongation. The problems involved in production of a pressure-tight circumferential seam are discussed and the progress made towards their solution indicated.

"Some Extracted Notes on Hastelloy Fabrication and Welding"

The material for this report was originally prepared by the Development and Liaison Department in answer to a Member's query. It is thought, however, that the information would be of general interest.

Hastelloy high-strength nickel-base alloys are a series of four alloys, designated by the letters A, B, C and D, and have been developed to stand severe chemical corrosion. They are available as castings, standard mill forms and welding rod and can be fabricated into chemical equipment such as tanks, autoclaves, heat exchangers and coils, etc. A table is given showing principal welding features of Hastelloy alloys.

New Members

The following new members have been elected:—

British Transport Commission.
Thos. Broadbent & Sons Ltd.
Cleveland Bridge & Engineering Co. Ltd.
Coras Iompair Eireann.
Folland Aircraft Ltd.
Siemens-Schuckert (Great Britain) Ltd.
Widnes Foundry & Engineering Co. Ltd.

B.W.R.A. Fifth Annual General Meeting

The Fifth Annual General Meeting of the Association was held at the Research Station, Abington, near Cambridge, on Thursday, 13th July, 1950, when the Report of the Council, statement of accounts for the year to 31st March, 1950, and Balance Sheets as at 31st March, 1950, were received and adopted. Dr. J. H. Paterson, introducing the report, expressed the Council's satisfaction with the progress of researches; the new work undertaken by the Research Board during the year had already proved its value, and as the laboratory facilities and equipment increased, so the Association's contribution to the welfare of the Welding Industry and to the nation's industries as a whole would be a very substantial one.

The Liaison Department had been reorganised and placed on a firm footing; the belief of the Council that it would usefully supplement the work of the Association by bringing the results of its work to bear directly on Members' problems had been fully justified.

The Council was anxious to obtain the most modern

types of testing plant vital to its work and recorded with pleasure that a pulsating pressure testing plant, for fatigue testing pressure vessels, had been installed and a large tensile testing machine had been placed on order. These large and expensive equipments, however, demanded considerable laboratory space, and the Council was therefore planning to build a fatigue testing laboratory at Abington, thus releasing a portion of the old laboratories for much-needed expansion of other work. This new laboratory would cost in the neighbourhood of £20,000—a sum much beyond the amount which the Association could spare from its reserves, and an appeal for support would have to be made. The Chairman expressed the hope that members would consider what they could do to help in the building of this laboratory and in increasing the membership of the Association.

The Chairman recorded the Council's high appreciation of the work done by the Research Board and members of the various committees, and also of the quality and high standard of the work of the Director and Staff. He announced that Sir Stanley V. Goodall, K.C.B., O.B.E., had consented to be Vice-President and welcomed Sir Charles Lillicrap, K.C.B., who would be the new Chairman of the Council.

At the termination of the meeting, parties were escorted round the laboratories, where members of the staff demonstrated the apparatus and researches in progress.

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This booklet covers recommended spot weld dimensions, electrodes, welding pressure, welding time, welding current, forging time, fluctuations in the value of the variables, weld pitch, weld strength, edge distance, etc. A table of recommended settings is given. *Price 1/6, post free.*

All the above publications are obtainable from the

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R.59

The Welding of Thick Aluminium Alloy Plates by the Argon Arc Process

By J. E. CHARD, B.Sc.(Eng.), A.R.S.M., A.I.M., and N. MACDONALD

(Royal Naval Scientific Service)

SUMMARY

Argon arc welding equipment designed for operation with welding currents up to 600 amps. has been developed, together with suitable electrically controlled manipulating gear to enable mechanical (automatic) welding of longitudinal and circumferential seams. Welding technique for A.W.10 alloy has been developed to produce welds in plate up to ½ in. thick which, after heat-treatment, give tensile properties equal to those of the parent plate, apart from a reduced percentage elongation. The problems involved in production of a pressure-tight circumferential seam are discussed and the progress made towards their solution indicated.

1. INTRODUCTION

Arising from an Admiralty requirement for a high strength pressure vessel of welded aluminium alloy construction, development work has been carried out to establish the most suitable process and the necessary special technique for producing high efficiency welds in aluminium alloy plate of thicknesses up to ½ in. The alloy selected was STA.7/A.W.10 (B.S.1470: 1948—H.S.10) and work has been directed to producing welds using a filler rod of similar composition to the parent plate with a view to developing maximum strength by heat treatment after welding, and also to avoid the dangers of electrolytic corrosion. On test plates of ½ in. and ¼ in. thickness, it has been possible to produce consistently welds showing a 0·1 per cent. proof stress value of 16-17 tons per sq. in. with an ultimate tensile strength of upwards of 20 tons per sq. in., with 4 to 5 per cent. elongation. A considerable amount of preliminary work has also been done on the production of small experimental pressure vessels, but some problems still remain to be solved.

Some experimental work was carried out into the possibilities of applying gas welding (oxy-acetylene and oxy-hydrogen) for the purpose, but the results were not very promising and there was a pronounced tendency to cracking of the weld. The metallic arc welding process was found to give much better results and welded test plates having excellent properties were produced. There were, however, obvious disadvantages of this process in the production of actual welded containers owing to the relatively short run obtainable from a given electrode (with the necessity for chipping out of slag before recommencing to weld), while the process suffered, in common with gas welding, from the danger of possible flux entrapment in the weld. Following this preliminary work, it was decided that the argon arc process offered the most promise of success, and effort has been concentrated on the development of this process.

When it was decided to concentrate on the argon arc process for this application, no commercial equipment was available in this country suitable for welding plate thicker than about 3/16 in. using an air-cooled torch. Consequently, action was taken to design and make a water-cooled torch which enabled welding currents up to about 300 amps. to be employed—i.e., of sufficient power to enable plates up to ½ in. thickness to be welded successfully with a single pass. Following the promising results obtained during this preliminary stage of the work, it was decided in May, 1949, that it would be necessary to have equipment capable of a maximum welding current of about 600 amps to enable the work to be extended to plates of ½ in. thickness. A suitable torch was therefore designed and made, and the necessary electrical installation provided, the new equipment being brought into operation in September, 1949. At the same time, it was decided that to ensure reproducible welds (both longitudinal and circumferential), it was most desirable to arrange for some form of mechanical or automatic welding and an old lathe was adapted for this purpose and provided with suitable electric controls, both for movement of the job relative to the welding head and also for mechanical feeding of the filler wire. Automatic control of the argon supply was also provided to ensure the utmost economy. This manipulating equipment was brought into use about the same time as the higher capacity welding set.

2. DEVELOPMENT OF EQUIPMENT

(a) Torch Design

The original 300-amp. water-cooled torch designed and made in the Establishment employed a water-cooled handle and electrode holder with a refractory argon shield. It was found that the refractory shields commercially available at the time did not withstand operating conditions for an acceptably long period and the design was therefore modified to employ a cylindrical shield of fused silica. These silica sheaths were readily made by cutting lengths of fused silica tubing and they were held in position in the torch by two pins engaging in grooves ground in the external surface of the silica sheath. This arrangement proved quite satisfactory and the fused silica sheaths gave a much longer life. Commercially available electrolytic condensers and high frequency spark gap equipment were employed. When it was decided to proceed with the design of a torch capable of handling 600 amps., the opportunity was taken for a complete redesign embodying some features to facilitate production. The new torch contained no refractory components, the argon shield being made of water-cooled copper insulated from the torch body by a machined sleeve made from ebonite, the design being so arranged that this was not subjected to any heat. The water cooling for the copper argon shield passed through short rubber pipes from the torch head, these providing the necessary insulation. Fig. 1 shows the general arrangement of the torch, which has proved entirely satisfactory with welding currents up to 600 amps. Provision was made for the use of tungsten electrodes up to 7/16 in. diameter, smaller electrodes being catered for by means of suitable collets. As anticipated, a tungsten electrode of ½ in. diameter has proved adequate for carrying welding currents up to 570 amps. without becoming unduly overloaded and a welding current of this order has been found adequate for producing single pass welds in ½ in. plate.

One advantage of employing a water-cooled copper argon shield was that it was possible by simple machining operations to vary the internal shape and dimensions of the shield, and some work has been carried out with a view to establishing the most efficient form of hood from the point of view of producing clean welds with the minimum argon consumption. It has been possible to produce satisfactory welds in ½ in. thick plate at a current of about 320 amps. (using a 7/32 in. diameter electrode) with an argon consumption down to 6 litres per minute; and in ½ in. thick plate with welding currents of about 530 amps. (using a ¼ in. diameter electrode) with an argon consumption of 12 litres per minute. It is hoped that the latter figure may still be improved upon by modified shield design. It is, however, too early to say whether much advantage is obtainable from a specially shaped shield.

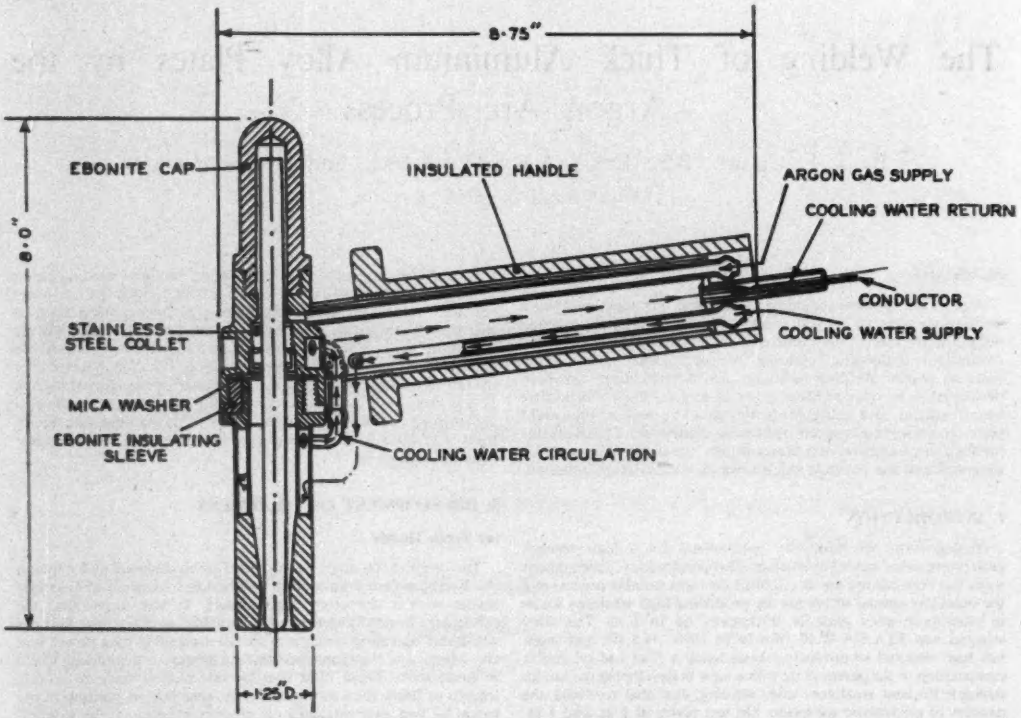

Fig. 1. Argon arc welding torch design.

The type of argon shield employed experimentally was on the lines of a convergent-divergent nozzle, as it was thought that this offered the possibility of producing a more stable argon flow at low consumption than would be possible with a simple parallel hood. It was found that the angle of the cone was fairly critical, as was also the position of the end of the electrode relative to the mouth of the shield. One interesting phenomenon which was experienced with one design of hood was that at the end of welding, as the electrode cooled below approximately 1000 deg. C., a dense white fume was evolved which continued until the temperature of the electrode had fallen to approximately 800 deg. C., when it abruptly ceased. This was at first puzzling, but was traced to oxidation of the tungsten, the fume being found to be over 90 per cent. tungstic oxide. The source of the oxidising atmosphere producing this fume was at first suspected to be contamination of the argon, but it was eventually proved to be due to entrained atmospheric air being drawn in at the mouth of the hood. During welding, the high temperature of the arc presumably caused sufficient expansion of the argon to avoid such introduction of air, but, on cooling down after welding, this expansion effect no longer operated, with the result that oxidation commenced. Slight modification of the cone angle of the shield completely cured this trouble. Any turbulence in the argon flow will, of course, also tend to produce oxidation of the weld itself.

(b) Manipulating Equipment and Controls

It was possible to obtain an old lathe, scheduled for scrapping, which proved eminently suitable for conversion to a manipulator. The lathe was provided with variable cone pulleys, as well as a fast and low-speed gear change, which enabled a wide range of speeds to be obtained both for rotation of the chuck (for circumferential welds) and movement of the saddle (for longitudinal welds). The lathe was driven through a high ratio reduction gear from a small electric motor. To provide ease of control, it was decided to employ direct current, and a small redundant 1 H.P. motor generator set was installed which provided a supply at 110 volts D.C. This was used for the manipulator drive and also, through a suitable resistance, for operating the wire feed motor and the automatic argon supply valve. Variable electric speed controls for the manipulator movement and also for the wire feed motor were mounted on a small panel coupled to the machine by a flexible lead, so that the controls could be placed in the most convenient position for the operator for both circumferential and longitudinal welding. Figs. 2 and 3 show general views of the machine and electrical equipment. Fig. 5 shows the control panel in more detail. The left-hand speed control governs the manipulator, while the small knob on the right governs the rate of wire feed. The operation of the switch seen in the centre of the control panel turns on the argon supply to the preset value for welding, move-

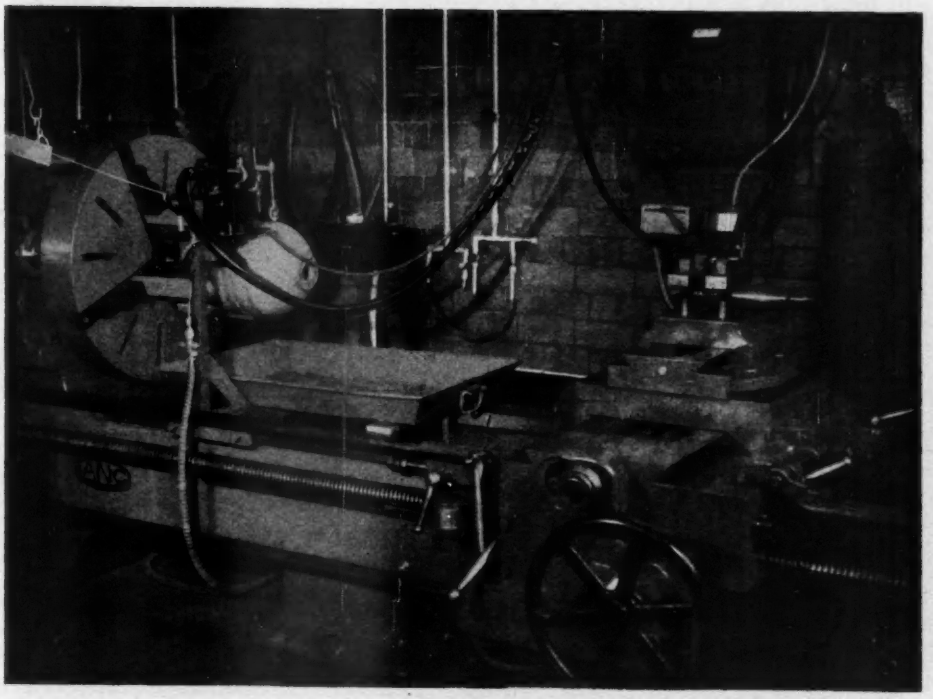

Fig. 2. General view of welding machine.

ment of the valve operating a red indicator light (seen on the left at the back of the control panel). At the completion of welding, switching off this switch stops the manipulator, but by means of a suitable thermal delay unit, the argon is maintained at full flow for a further predetermined period to enable the welding arc to be maintained, if desired, for a short period after the machine is stopped and to initiate cooling down of the tungsten after welding is completed. At the end of this period, the argon supply is automatically cut down to a low figure (3 litres per minute), which is adequate to prevent oxidation of the tungsten during cooling, and this lower rate of flow is maintained for a further pre-set period, after which the argon is automatically shut off. The lower rate of flow is indicated by the right hand (amber) indicator lamp on the back of the control panel). Fig. 4 shows the electric argon control valve and (on the left) the thermal delay unit. Figs. 6 and 7 respectively show the machine set up for circumferential and longitudinal welds. It will be seen that the torch is designed to run with rollers on the actual job to ensure a constant arc length, and to compensate for any slight irregularity or ovality in the surface, and is capable of being lifted by means of a cam by a lever at the top. At the conclusion of welding, the torch is raised by operation of this lever and the welding arc broken. Starting of the welding arc is effected by the use of a small carbon wedge introduced under the tungsten electrode.

Water supply for cooling the torch is taken through a suitable orifice which ensures the correct rate of flow without the necessity for any adjustment of the supply valve. The back pressure from this orifice operates a suitable water interlock (seen in Fig. 3), which prevents the main welding current being switched on unless the water supply is flowing. The cooling water passes over a suitable fuse to provide protection in the event of failure of the mains supply.

(c) Welding Current

Owing to the fact that a 600-amp. welding transformer was not available, it was necessary to connect in parallel two 300-amp. transformers of similar design, each provided with a suitable bank of electrolytic condensers. By employing one or both of these transformers, it is possible to obtain a range of welding currents up to 600 amps.

(d) Welding Rate

The rate of welding is dependent upon the current employed and the dimensions of the work piece. In making single-run welds in $\frac{1}{2}$ in. thick test plates with a current of 530 amps., a rate of 4 in. per minute has been found satisfactory. A similar speed is suitable for single-run welds in $\frac{3}{8}$-in. plate at a current of 320 amps, but faster rates are obtainable by the use of an increased welding current. (Test plates employed were 24 by 7 in.)

3. WELDING TECHNIQUE

The investigations by the Aluminium Development Association Team at Birmingham University* confirmed that A.W.10 alloy was very prone to weld cracking, and it was realised that considerable

* P. H. Jennings, A. R. E. Singer and W. I. Pumphrey, J. Inst. Metals, 1948, 74 (5), 227.

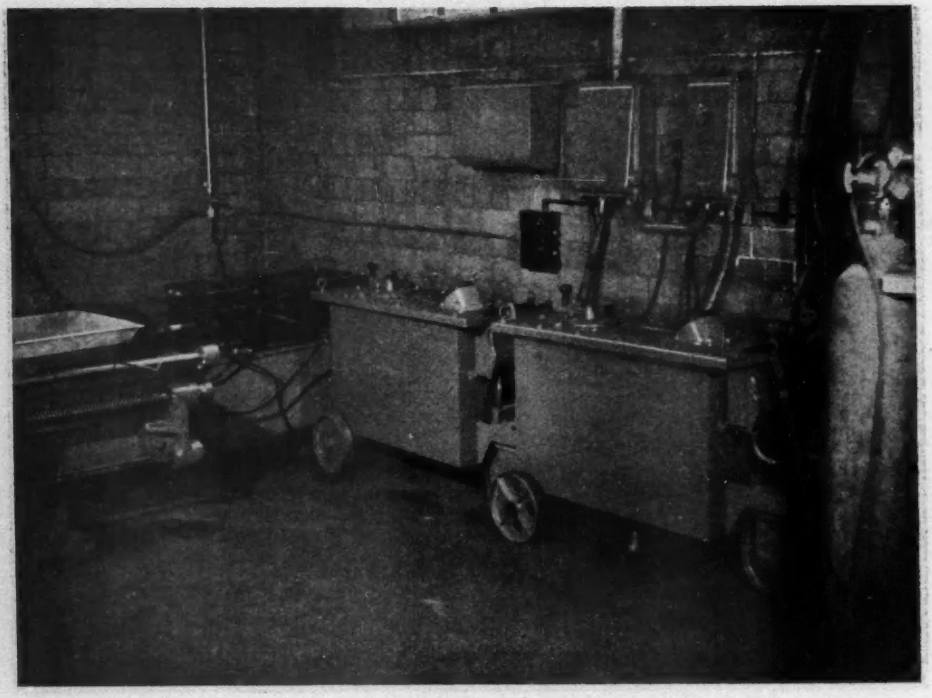

Fig. 3. Electrical equipment.

development of technique would be necessary if success was to be achieved with this alloy, particularly when welded with a filler rod of similar composition and in the case of plates of relatively great thickness.

The preliminary work carried out with gas welding and metallic arc welding showed that if plates to be welded were preheated appreciably above 150 deg. C., there was a great liability for cracking to develop through the centre of the weld. Provided, on the other hand, the preheat temperature was kept below this figure, cracking of the weld did not present a difficulty. This conclusion has been confirmed by subsequent work with the argon arc process. While in the case of thin plates, it is advantageous to work without preheat, in the case of thicker plates (above ¼ in.) a light preheat is desirable to facilitate proper fusion at the commencement of welding and to accelerate the welding rate.

At first a 60 deg. "V" preparation was employed in the case of plates of ¼ in. thickness, but difficulty was experienced due to a tendency for oxide entrapment on the fusion faces. This tendency was found to be materially reduced if no preparation was employed and the plates were butted together as closely as possible for welding. This technique has been found successful also in the case of ¼ in. thick plates in which satisfactory welds are produced by butting the edges together without any "V" preparation. On the other hand, some satisfactory welds have been produced with ¼ in. plate in which there was a small "V" preparation extending about ⅛ in. deep (i.e., with ⅛ in. root face). There is, however, no advantage from this preparation provided adequate power is available and simple butting of the edges to be welded has been adopted as standard. At first, great care was taken to clean the surfaces to be welded by pickling and/or scratch brushing, but it has been found that, provided a reasonable standard of cleanliness is observed (i.e., degreasing), such precautions are not essential and, experimentally, surprisingly satisfactory welds have been produced from scrap plates welded without any preliminary cleaning whatever.

In the early work on thick (¼ in.) plates, considerable difficulty was experienced due to traces of oxide left in the root of the weld. It was found advantageous to employ a grooved steel backing strip to support the weld as this assisted the displacement of any such traces of oxide into the groove and out of the weld proper. There were the further advantages that the efficiency of fusion could be readily judged by observing, after welding, whether the groove in the backing strip had been completely filled, giving a continuous rib, while the latter resulted in an increased cross section of weld, constituting an appreciable reinforcement of section. In the case of thick plates, with hand operation of the torch it was difficult to ensure that the arc was directed uniformly to the edges of both plates, with the result that sometimes there was a tendency for lack of proper fusion at the root on one or other of the plates. It was this consideration which chiefly determined the decision to construct a machine for mechanical or automatic welding in order that the torch could be set accurately with reference to the plates to be joined.

Considerable trouble was experienced from time to time due to the erratic behaviour of the arc which deflected to a marked degree to one side or the other of the seam, sometimes for a considerable distance, in mechanical welding. This was very serious as proper fusion of the two plates was not, of course, obtained. After a considerable amount of experimental work, this trouble was traced to a magnetic effect associated with the return path of the current to earth relative to the position of the arc. Any arrangement giving a current carrying loop in the line of the weld resulted in

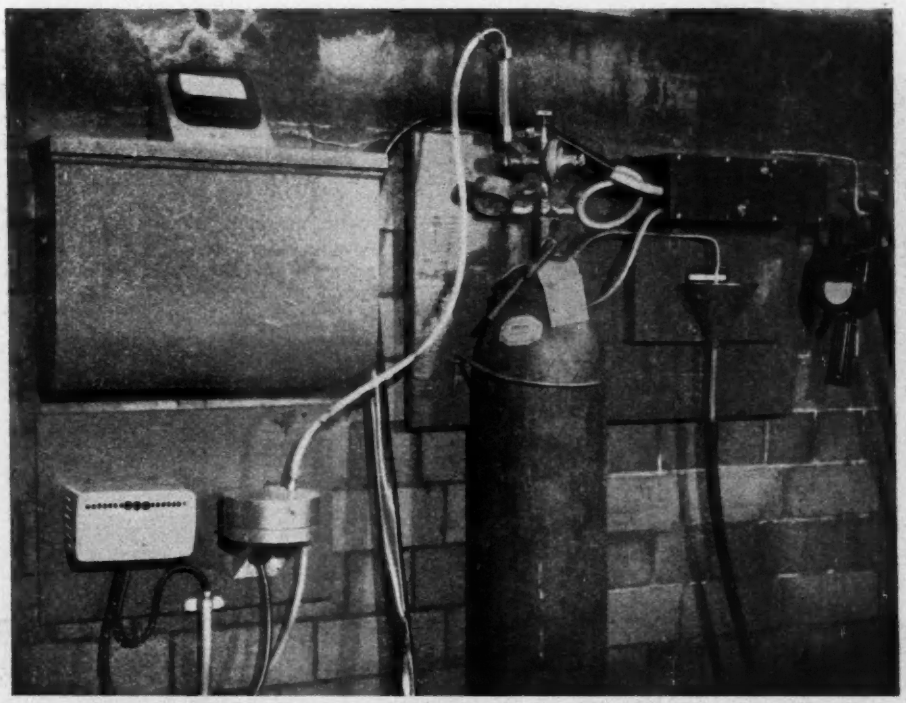

Fig. 4. Argon control valves, thermal relay, clip-on ammeter (*right*) and voltmeter (*left*).

deflection of the arc, and it was found possible to produce deflection in either direction by suitable positioning of the earth cable and clamps. By careful positioning of the earth clamps on the work, it was possible to overcome this effect.

A few experiments have been carried out to establish the optimum heat treatment for welded plates with a view to developing the required mechanical properties. It was at first thought that owing to the fact that the weld was a cast structure and that the adjoining parent plate would be over-precipitated due to the heat of welding, a prolonged period (e.g., 4 hours) of solution treatment would be necessary. Mechanical tests obtained on welded plates heat treated in this way gave an 0·1 per cent. proof stress value of approximately 14 to 15 tons per sq. in. with ultimate tensile strengths of 17 to 18 tons per sq. in. and 5 to 8 per cent. elongation. Subsequent work indicated that there was no advantage from a prolonged soaking time, and, in fact, improved proof stress results were obtained by keeping the solution treatment time short and increasing slightly the temperature (i.e., working at the top of the recommended temperature range—535 deg. C.). There was some indication that a rather long precipitation treatment was advantageous. The following table gives some typical mechanical properties obtained on welded plates solution treated at 535 deg. C. for three-quarters of an hour, followed by precipitation treatment at 170 deg. C. for 14 hours. (In the case of welded test plates, before tensile tests were carried out, the metal was milled down on both faces to remove any reinforcement of section and to ensure a parallel test plate, the minimum possible amount of metal being removed to ensure this.)

Specimen No.	Thickness of Plate as Welded	Test Piece Dimensions	0·1 per cent. Proof Stress (tons per sq. in.)	Ultimate Tensile Strength (tons per sq. in.)	Elongation per cent.
AA.16-1	$\frac{3}{8}$ in.	·997 in. × ·307 in.	16·7	20·0	5·5
2	$\frac{3}{8}$ „	1·0 „ × ·278 „	16·4	20·3	8·5
3	$\frac{3}{8}$ „	1·0 „ × ·324 „	16·8	20·3	7·75
AA.14-1	$\frac{5}{8}$ „	·991 „ × ·573 „	17·0	20·3	4·5
2	$\frac{5}{8}$ „	·998 „ × ·581 „	17·1	20·0	4·5
B.S. 1470: H.S. 10 W.P. (Sheet and Strip) Specification Requirements			15 min.	19 min.	8 min.

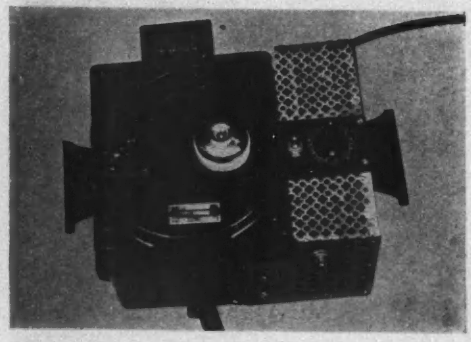

Fig. 5. Control panel.

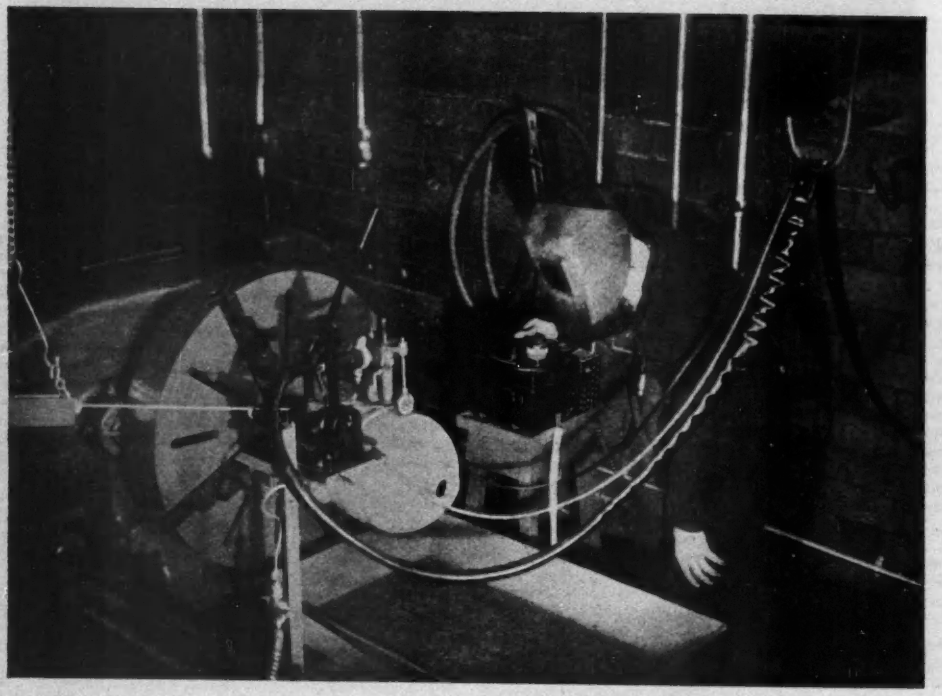

Fig. 6. Machine set up for circumferential welds.

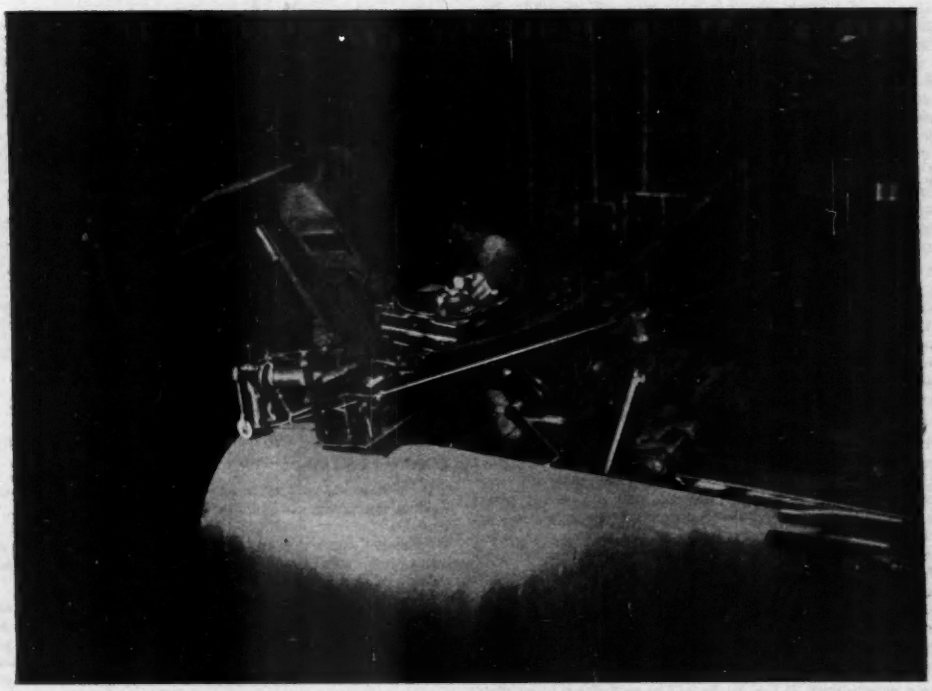

Fig. 7. Machine set up for longitudinal welds.

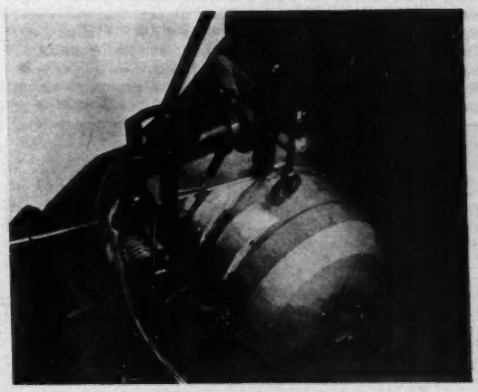

Fig. 8. "Run-out plate" and ramp assembly.

The problems involved in producing a circumferential weld in a vessel are different from, and greater than, those in the production of a satisfactory longitudinal weld between two plates. In particular, there is the difficulty of heat build-up as the end of the weld is reached and, finally, the problem of ending the weld without production of a crack, particularly as there will inevitably be a crater crack where the weld is stopped. Consequently, at a fairly early stage in the development a number of small pressed cups (11 in. external diameter) of A.W.10 alloy were made, having a wall thickness which could be machined either to ¼ in. or ⅛ in. to enable actual experience to be gained on the problems of producing a circumferential weld and to provide a basis for full-scale work. It was found possible to produce circumferential welds on these small bottles having a very good and uniform appearance and satisfactory penetration, but in every case there was a small crack at the position in which the weld stopped. This crack caused failure of the bottles under pressure test by leaking, although pressures up to 2000 lbs. per sq. in. did not reveal any serious structural weakness of the weld itself.

It was considered that this terminal crack was essentially a shrinkage crack, resulting from the fact that the last molten metal deposited was not "fed", and some attempts were made to build up a small "feeding head" with weld metal at the end of the run to overcome this difficulty by torch manipulation. This did not, however, prove successful. A few experiments were conducted in an attempt to provide an actual refractory lined feeding head at the end of welding which was filled with molten metal from a crucible, but this proved cumbersome and not very satisfactory.

Following the lines indicated by the work of the Welding Research Team at Birmingham University, one or two welds were carried out with a filler rod of modified composition (i.e., with somewhat higher silicon and magnesium content than the parent plate) with a view to producing a weld deposit of lower tendency to cracking. The modified composition filler rod appeared on visual examination to have resulted in an improvement, there being no visible crack. However, on pressure test, the bottle leaked and closer examination of the weld revealed the presence of fine cracks. Consideration was also given to employing a double run technique, as it was thought that the smaller volume of liquid metal present at the end of the run in this case would be beneficial.

A possible solution was recently evolved employing a tapered run-out plate (shown in Fig. 8). As will be seen, the run-out plate has a thin-pointed end carrying a groove into which the filler wire fits as the rotation of the bottle brings the run-out plate under the torch. As soon as the tip of the run-out plate starts to fuse, thus providing filler metal, the filler wire is withdrawn and the arc fuses a progressively greater quantity of metal from the run-out plate, while being raised above the level of the bottle as one of the wheels carrying the torch runs up the ramp attached to the run-out plate. This method has resulted in the satisfactory feeding of the end of the weld and three bottles having a wall thickness of ¼ in. were welded in this way in succession which were completely pressure tight up to pressures of 2,300, 2,400 and 2,600 lbs. per sq. in. respectively. (These figures compare with the calculated pressure for yield of 2,350 lbs. per sq. in., based on an 0·1 per cent. proof stress value of 15 tons per sq. in.) The procedure was to commence welding as usual and to clip on the run-out plate/ramp assembly while the machine was running after approximately one-quarter of the weld had been completed, so that the run-out plate covered the weld which had already been deposited. Fig. 9 shows the appearance of the run-out plate on the completion of welding.

It is thought that there may perhaps be some further advantage in employing a run-out plate of modified composition and containing a grain-refining agent with a view to providing the maximum possible soundness at the end of the weld.

Fig. 9. "Run-out plate" at conclusion of welding.

4. CONCLUSIONS

It has been shown that the construction of an efficient argon arc welding equipment for welding currents up to 600 amps., and designed for the mechanical welding of circumferential and longitudinal seams, does not present any undue difficulty and there seems every reason why this process should find increasing use for welding of aluminium and its alloys.

It has been shown that sound and reproducible welds can be made in A.W.10 plate up to ¼ in. thickness, using a filler rod of similar composition, which will give mechanical properties equal to those of the parent plate as regards proof stress and ultimate tensile strength and with acceptable ductility. (On two occasions tests showed fractures in the parent metal in preference to the weld.)

While the problems involved in production of satisfactory circumferential welds for pressure vessels in A.W.10 alloy have not yet been entirely overcome, work is proceeding on lines which, it is hoped, will provide a solution to these problems.

It is fully realised that many aspects touched on in this report require much fuller investigation, but it is hoped that it may serve a useful purpose as a basis for discussion.

5. ACKNOWLEDGMENTS

It is desired to record appreciation of the assistance and encouragement received from colleagues and also of the co-operation shown by representatives of the British Welding Research Association, the Northern Aluminium Company and the British Oxygen Company, and of Dr. West of Aluminium Development Association, and Dr. Pumphrey and Mr. Moore of Birmingham University.

The authors are indebted to the Chief of the Royal Naval Scientific Service for permission to publish this paper.

R.60

Some Extracted Notes on Hastelloy Fabrication and Welding

Hastelloy high-strength nickel-base alloys are a series of four alloys, designated by the letters A, B, C and D, that have been developed to withstand severe chemical corrosion, including the common mineral acids, such as hydrochloric and sulphuric. They are available as castings, welding rod and standard mill forms that can be fabricated into chemical equipment such as tanks, autoclaves, heat exchangers and coils.

Table I. Principal Welding Features of Hastelloy Alloys

Hastelloy Alloy	Composition Per Cent.	Weldable Forms	Welding Process	Handling	Average Rockwell Hardness
A	Ni-57 Mo-20 Fe-20 Si-1, Mn-2 C.15	Cast	O-A	HCl	B-92
		Wrought or Rolled	(1) M-A (2) O-A R		B-96
B	Ni-62·5 Mo-30 Fe-5 C·02-·12	Cast	O-A	Hot HCl	B-95
		Wrought or Rolled	(1) M-A (2) O-A R		B-98
C	Ni-Bal Mo-15 Cr-15 W-5 Fe-5 C-.04/.15	Wrought Cast	(1) O-A (2) M-A	Wet Cl_2	B-93
		Rolled	(1) M-A R		B-91
D	Ni-Bal Si-10 Cu-1 Al-1	Cast	O-A	H_2SO_4	C-52

O = Oxyacetylene A = Atomic Hydrogen
M = Metal arc R = Resistance

All four of these Hastelloy alloys are supplied in a variety of forms. Alloys A and B are supplied in the form of hot-rolled sheet and plate; forgings; welded tubing; welding rod (alloy B only); wire; and castings such as cast pipe, fittings, and valve and pump parts. Because these two alloys can be hot rolled and forged, they are fabricated into many kinds of equipment.

Hastelloy alloy C is available in hot-rolled sheet and plate but cannot be supplied in forgings or hot-rolled bars. Hastelloy alloy D is supplied in the form of castings only.

Hastelloy alloys A and B are also available in the form of drawn wire. Hastelloy alloy C has been drawn only experimentally into wire form.

The Hastelloy alloys are not available in clad sheet, although some experimental rolling has been done.

Hastelloy alloys can be readily fabricated by the same methods as those used for stainless steel, Monel and other high-alloy materials, however, these alloys require careful handling in order to avoid such conditions as cracking, and lessened corrosion resistance resulting from carbon pickup or improper heat treatment.

The uses of these alloys, Hastelloy alloys A and B—developed primarily for corrosion resistance to hydrochloric acid—also have resistance to sulphuric acid, phosphoric acid, acetic acid and many organic chemicals. Alloy A is for relatively low-temperature applications. Hastelloy alloy B can be used in handling all concentrations of hydrochloric acid at temperatures up to and including the boiling point.

Alloy C has been used for handling sulphuric acid, hydrochloric acid, mixtures of nitric and sulphuric acid, and especially for oxidising agents such as ferric chloride, cupric chloride, wet chlorine gas and organic chemicals.

Hastelloy alloy D is used chiefly for handling hot sulphuric acid, but it has good resistance to phosphoric, cold hydrochloric and many other acids.

Hastelloy alloys can be readily fabricated by oxyacetylene, atomic-hydrogen, Heliarc, resistance, automatic and metallic arc welding.

The physical properties of these alloys make careful technique as well as proper sequence of welding operations particularly important. In most cases, heat treatment is desirable so as not to impair the corrosion resistance.

The corrosion resistance properties are only developed after welding, by heat treatment. Heat treatment is not necessary when the equipment is to be exposed to mild forms of corrosion. Where corrosion is a particular problem, heat treatment is usually necessary.

In the welding of Hastelloy alloys A, B and C, it is most important that a neutral flame is maintained during welding to avoid carbon pickup. Atomic hydrogen, and Heliarc welding have proved superior to the oxyacetylene welding process. It is desirable to preheat castings to a dull red heat before welding to avoid causing excessive stresses. Such practice should be followed by a full anneal of the material, because holding the alloys at red heat for any appreciable length of time impairs their corrosion resistance.

Very rarely is cracking trouble encountered in welding a Hastelloy alloy vessel. The possibility of cracking is much more likely in lining work.

Although cracking trouble in welding Hastelloy alloys is negligible and occurs only when care is not taken to avoid excessive stresses, the sequence of welding operations should be planned carefully. It is apparent that the material does not crack from the stresses after reaching room temperature, but it does crack when severely stressed at elevated temperatures.

In the wrought form, Hastelloy alloys A, B and C can generally be worked in the same manner in which stainless steel, Monel and other similar high alloys are fabricated. The strength of these materials at elevated temperatures and their hot-short properties in a range of 1200 deg. to 1800 deg. F. make the working somewhat more difficult. Fabrication techniques used for stainless steel can be adapted to Hastelloy alloys A, B and C, and these alloys can be formed, bent, deep-drawn, and spun, as well as welded.

The metallic-arc, atomic-hydrogen and oxyacetylene processes have all been used but the metallic-arc process is preferable using reversed polarity with a coated rod. Heavily coated electrodes of the same analysis as parent metal are recommended, although Hastelloy B electrodes can be used on Hastelloy A metal to secure better corrosion resistance. These alloys flow very well under the metallic arc, and form a good-looking weld with a nice cover bead and excellent penetration.

The most satisfactory all-round welding process for sheet and plate of Hastelloy alloys A, B and C is the metallic-arc process.

In arc welding Hastelloy alloys, it is recommended that the welding be done rapidly with as little current as possible; also, that the arc be choked short and the electrode be worked away from the molten puddle.

The principal difficulty with the atomic-hydrogen process for these alloys, is controlling the heat, to prevent overheating the weld metal and the areas adjacent to the weld.

Carbon pickup is particularly detrimental to Hastelloy C, because this alloy contains chromium and thus picks up carbon much more readily. Because of the physical characteristics of Hastelloy alloy D, the oxyacetylene process is the only suitable method for welding in ordinary production.

Molten alloy D, like cast iron, is quite fluid, so that a welding operator who knows how to weld cast iron should have little difficulty when welding Hastelloy alloy D.

All castings of Hastelloy D should be preheated to a temperature of approximately 1400 deg. F.

Welding with such gases as propane and hydrogen has been done, but with little advantage, if any, over the oxyacetylene or atomic-hydrogen processes.

The alloys will work harden quite rapidly as compared to stainless steel, and in general only approximately 50 per cent. of the working that is possible to perform on stainless steel can be done on Hastelloy alloys. In forming sheet or plate it is desirable to do most of the work cold. If hot working is performed it is essential that the work be carried out at temperatures above 1900 deg. F. to avoid cracking during the forming operations.

Only two of the standard heat treatments will be mentioned, "full anneal" and "stabilising anneal." On Hastelloy alloys A and B a "full anneal" consists of holding at a temperature of 2100 deg. to 2150 deg. F. for twenty minutes to one-and-a-half hours, and cooling rapidly in air or quenching heavy sections in water; for Hastelloy alloy C, the temperature is a little higher—2200 deg. to 2225 deg. F.—for two to three hours.

The stabilising anneal is used before welding A, B or C sheet to prevent deterioration adjacent to welds when heat treatment after welding is not practical. It is also used after welding to reduce the loss of corrosion resistance and toughness. This treatment is most effective when preceded by the full anneal. For alloys A and B, it consists of holding at a temperature between 1925 deg. and 1950 deg. F. for two to four hours and air cooling. Alloy C should be held for the same time at the temperature of 2050 deg. to 2075 deg. F. and also cooled in air.

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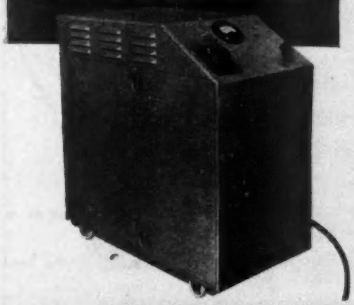

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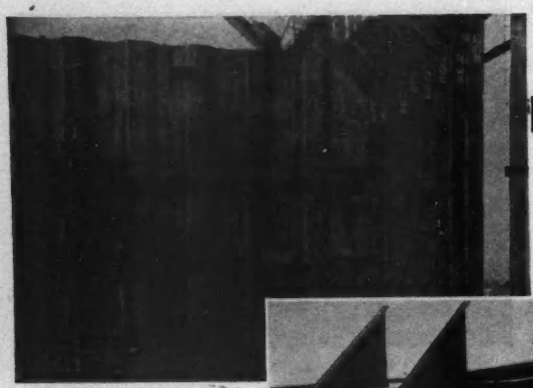

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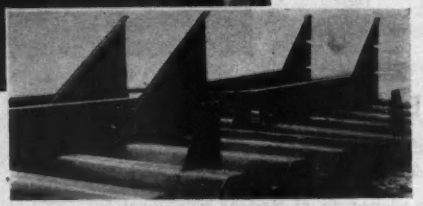

Large illustration: TRANSVERSE BULKHEAD IN POSITION.
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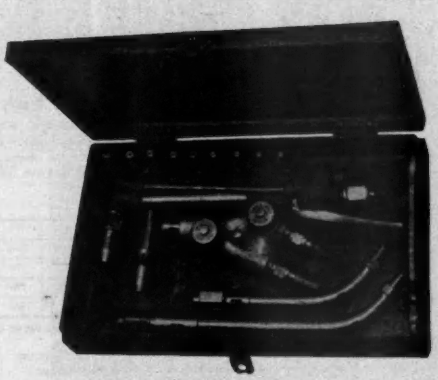

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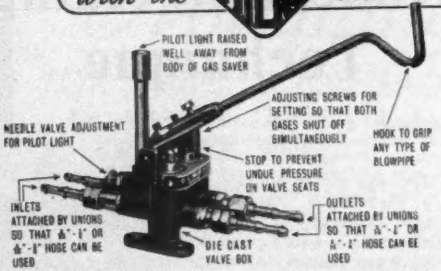
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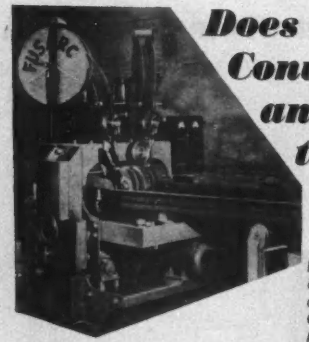

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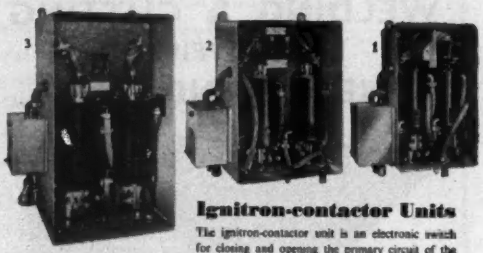

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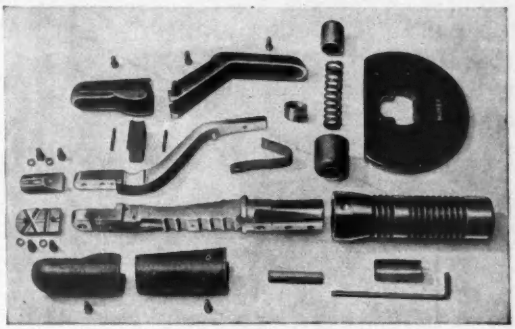

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